23/J

THE SCIENCE REPORTS OF THE RESEARCH INSTITUTES
TÔHOKU UNIVERSITY SERIES D (Agriculture)

THE REPORTS OF THE INSTITUTE FOR AGRICULTURAL RESEARCH

TÔHOKU UNIVERSITY

Vol. 1-2
1950

31 MAR 1950

Published by
Tôhoku University, Sendai, Japan
(Rep. Inst. Agr. Res. Tôhoku Univ.)

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All communications for the Reports should be addressed to the Director J. Kimura, the Institute for Agricultural Research Tohoku University, Sendai, Japan.

Studies on the Mechanisms of Phosphorus and Iron Absorption by Rice Plant. I*

Jiro KIMURA and Hideo OKAJIMA

(Received July 1, 1950)

I. Introduction

The physiological function of phosphorus for the crops has been studied extensively for many years. One of the authors[1][2] also studied the role of phosphorus in the rice crop with the solution culture, compared it with that of barley, and, from the results of various experiments, found that the rice plant seedlings distinctly differed from barley in the absorption of phosphorus and iron, and proposed a hypothesis as follows: "The P_2O_5 absorbed excessively by rice seedlings grown in the solution rich in this substance may act on iron in the plant tissues in such a way that the iron existing in the cell is turned into an inactive form and causes chlorosis and other physiological disturbance." But in the previous work the experimental proof for the existence of iron phosphate in the plant tissue was not given.

A. Fujiwara[3] studied the chemical forms of phosphorus and their physiological role in the rice plant, but he did not touch upon the problem which the authors have considered.

Recently valuable investigations as to the phosphorus absorptions have been conducted by many American workers using the tracer method of radioactive isotope, however, the formation of phosphorus inorganically bound with iron in the rice plant, which may be the cause of the injurious effect of phosphorus caused by its excessive absorption in rice, has not yet been proved.

The work reported here, was undertaken in an attempt to prove more directly the presence of iron phosphate in rice seedlings by microchemical test as well as to make the chemical analysis of the three fractions of the phosphorus — water soluble, dilute acid soluble (pH 3) and residual phosphorus — in the rice plant, especially in comparison with the barley plant seedlings which were cultured in nutrient solution with varied amounts of phosphorus and iron.

II. Experimental procedure

Seeds used in this study were "Norin 16" variety of rice and "Aizu 2" variety

* The 44th report of the Institute for Agricultural Research, Tohoku University. (1950)

of barley. After sterilization rice seeds were sown on the net which was paraffined and floated in the ordinary distilled water, and barley seeds were sown in the sand bed which was properly moistened with distilled water.

When the seedlings grew up 10-11 cm in height, after being selected for uniformity, 4 seedlings were transplanted to each culture jar of 500 cc capacity.

A series of this experiment was conducted with the combination of varied amounts of P_2O_5 and Fe_2O_3, respectively, and 8 series were made as shown in Table 1.

Table 1. Amount of phosphorus and iron component in culture solution.

Series	P_2O_5	Fe_2O_3	Source of iron
	p.p.m.	p.p.m.	
1	20	10	Ferric phosphate
2	150	10	,, ,,
3	20	0	Ferric citrate
4	20	10	,, ,,
5	20	50	,, ,,
6	150	0	,, ,,
7	150	10	,, ,,
8	150	50	,, ,,

Composition of nutrient solution in this experiment was the same as was employed in the previous study[1], as shown in Table 2.

Table 2. Composition of culture solutions.

P_2O_5	Salts contained in mg per litre of solution					Mol. proportions
	$(NH_4)_2SO_4$	$Ca(NO_3)_2$	$Mg(NO_3)_2$	KNO_3	$CaH_4(PO_4)_2$	$P_2O_5 : N_2O_5 : SO_3$
p.p.m.						
20	96.5	185.7	189.5	73.8	34.2	0.4 : 7.6 : 2.0
150	96.5	30.0	189.5	73.8	256.4	3.4 : 5.6 : 2.0

All the jars were placed in the green house and the solution was renewed twice a week. Microchemical test with the fresh plant tissue began when the plants were 25 days old and continued for a few days. After 30 days' culture, all the plants were harvested, and height of the plants, fresh weight and dry weight were determined. Then, the plants were prepared for chemical analysis, namely, phosphorus determination.

III. Experimental results

1. Effect of nutrient treatments on the plant growth and yield

(i) Rice

In the series of experiments with high phosphorus and no or low iron application (series 2 and 6), the plant showed poor growth, and after receiving nutrient solution

for 10 days, new leaves changed to yellow, and after 15 days, this phenomena became severe, and after 20 days, brown spots were found on the tips of green leaves. Throughout the culturing period the growth was retarded and injury caused by phosphoric acid was observed clearly. At the time of harvest all the leaves of the plant in series 2 showed chlorosis and looked very feeble spreading out sideways. The tips of the lower leaves had many brown spots and looked as if dead, and the roots were colored brownish white with little lateral roots.

In the series of experiments with low phosphorus and no or low iron application (series 1 and 3), the plants showed chlorosis on account of deficiency of iron 15 days after receiving nutrient solution. Even the plants in series 4 which were supplied with 10 p.p.m. Fe_2O_3 in the form of ferric citrate, turned somewhat yellow 20 days after transplanting. At the time of harvest, although the plants in series 1 displayed slightly yellowish color, those in series 3 showed severe chlorosis and the roots also were in bad condition, without any lateral and new roots. The plants in series 4 were generally in healthy condition, although slight yellowish color appeared between the veins of leaves and the roots were colored brownish with the precipitation of iron hydroxide.

In the series 5 (low phosphorus and high iron application) and in series 7 and 8 (high phosphorus and iron), all the plants made vigorous growth throughout the experimental period, and the roots showed healthy growth with abundant lateral roots with yellowish white color. Table 3 shows the yields of rice after 30 days' solution culture.

Table 3. Yield of the rice plant grown 30 days in solution culture with different amounts of phosphorus and iron. (Data are for 11 plants of rice. Oct. 17, 1949)

Series	Treatment		Length of tops	Length of roots	Fresh weight	Air dried weight
	P_2O_5	Fe_2O_3				
	p.p.m.	p.p.m.	cm	cm	g	g
1	20	10	30.6	11.6	8.2	1.2
2	150	10	28.3	10.6	7.9	1.0
3	20	0	31.0	12.6	6.4	0.9
4	20	10	37.1	18.8	13.0	1.6
5	20	50	39.3	15.6	16.0	2.1
6	150	0	24.6	10.1	5.0	0.7
7	150	10	39.3	19.1	20.0	2.7
8	150	50	41.3	16.6	20.0	2.7

(ii) Barley

There appeared some differences in growth from the 10th day after transplanting. On comparing the differences in growth caused by the varied phosphorus applications, it was found that a better growth was made in series 2 (high phosphorus) than in series 1 (low phosphorus), and this tendency continued until the end of culturing test. On the 20th day, though the plants in series 1 turned somewhat yellow,

those in series 2 kept the normal and healthy growth. This phenomenon was quite reverse in the case of rice culture.

Considering the difference in growth influenced by the varied iron application, the plants in series of 10 p.p.m. Fe_2O_3 application (series 4 and 7) made good growth in either low or high phosphorus application, and of these two series, especially the plants in series 7 made better growth than those in series 4.

On comparing the plant growth between no and 50 p.p.m. iron application, it was found that the plants in series without iron looked better in early stage, but after 20 days, those in series with 50 p.p.m. iron gradually became better than those in no iron series, although the plant growth in series 5 was gradually retarded from the 10th day after transplanting and even showed the deficiency of phosphorus. Data for the yields after 30 days culture were shown in Table 4.

Table 4. Yields of barley plants grown 30 days in solution culture with different amount of phosphorus and iron. (data are for 8 plants of barley Oct. 27, 1949)

Series	Treatment		Length of tops	Length of roots	Fresh weight	Air dried weight	Source of iron
	P_2O_5	Fe_2O_3					
	p.p.m.	p.p.m.	cm	cm	g	g	
1	20	10	32.5	21.2	15.0	1.27	Fe-phosphate
2	150	10	36.5	26.0	19.0	1.85	,, ,,
3	20	0	31.5	20.5	16.5	1.43	Fe-citrate
4	20	10	34.5	22.0	20.9	1.72	,, ,,
5	20	50	24.5	21.5	11.1	0.85	,, ,,
6	150	0	34.0	22.5	16.9	1.35	,, ,,
7	150	10	39.5	21.5	31.7	2.52	,, ,,
8	150	50	34.5	18.0	22.4	1.78	,, ,,

From the result, it will be seen that in barley plant growth, contrary to the rice plant growth, the higher the phosphorus concentration in solution was, the better the growth was. This phenomenon coincides with the results which were already published by the senior author[1] as well as by others. Moreover, barley showed different nutritive behavior from rice seedling with regard to iron nutrition, namely, barley in low iron series (10 p.p.m. Fe_2O_3) made better growth than that in high iron series (50 p.p.m. Fe_2O_3). In the case of rice plant growth this tendency was also quite reverse.

For reference, we attempted to determine the amount of soluble iron and phosphorus in the culture solution employed, as shown in Table 5. When the iron citrate was used as the iron source, solubility of iron was remarkably high as already known. However, according to the test for solubility 3 days after it was reduced markedly, as shown in Table 5. Probably most part of it might be precipitated as the ferric hydroxide with the lapse of time although some part of it might combine with phosphoric acid. At any rate, in the case of employing ferric citrate as the

iron source for culture solution, available iron and phosphorus are abundantly obtained in the solution.

Table 5. Solubility of phosphorus and iron in the culture solution.

Series	Treatment		Amount of sol. P_2O_5	Amount of sol. Fe_2O_3	
	P_2O_5	Fe_2O_3	After 3 days	Aafter 1 hour	After 3 days
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
1	20	10	16.72	0.34	0.30
2	150	10	141.21	0.35	0.40
4	20	10	13.35	——	3.70
5	20	50	2.41	36.05	3.30
7	150	10	114.01	8.78	1.02
8	150	50	115.06	35.68	0.49

2. Inorganically bound phosphorus in the plant tissue detected by the microchemical test

K. E. Wright[4] made the chemical test of the alminium phosphate under microscope in order to ascertain the presence of Al-phosphate in the barley plant tissue. According to this result inorganically bound phosphate was not observed in the plant when the culture solution did not contain the aluminium ion, but inorganically bound phosphorus was found abundantly in the root grown in the solution with aluminium ion. From this result he proved a possible combination of phosphate with aluminium in the plant tissue. We considered that analogous phenomena would take place between iron and phosphoric acid in the plant body grown in culture solutions and carried out the microchemical test.

The experimental procedure was conducted according to the modified method of Schneider-Zimmerman, as follows: sections of root, stem and leaf were cut by hand, on which 1 drop of ammonium molybdate solution, prepared by dissolving 1 g of ammonium molybdate in 12 ml of nitric acid of sp. gr. 1.18, was placed. On observing this reaction under the microscope, it was found that the formation of yellow crystals, mostly cubes and octahedrons, indicates the presence of inorganically bound phosphorus. As G. Klein[5] stated, the inorganically bound phosphate was found abundantly on the tips of newly developed roots while little or none in the side roots or upper part of the roots. Therefore, the present authors tried to test the upper part of young and old roots, the intermediate stems between 3rd and 4th leaves and the tips of the highest part of leaf (youngest leaf), as shown in Table 6 about rice and Table 7 about barley.

(i) Rice

From the results of microchemical test of inorganically bound phosphorus, it was found that the inorganic phosphate was more generally detected with the

increase of iron application to each part of the plant body. The inorganic phosphate was found more in the series of high phosphorus application when the iron was not applied than in the series 10 and 50 p.p.m. iron application (series 7 and 8). In comparing the inorganic phosphate present in young and old leaves, it was found that it could be detected generally less in the young leaves than in the old ones, and moreover, in old leaves the presence of inorganic phosphate did not show any significant dlfference. Inorganic phosphorus presented usually more in the stem than in the root and did not show any remarkable difference in the series of varied iron applications.

Table 6. Amounts of inorganic phosphorus in the tissues of roots, stems, and leaves of the rice plants grown four weeks by the microchemical tests. (Oct. 10, 1949)

Series	Treatment		Immediate	After 3 hours	Immediate	After 3 hours
	P_2O_5	Fe_2O_3				
	1) **Roots**		Young root		Old root	
	p.p.m.	p.p.m.				
1	20	10	0	0-+ S	0	0-+ S
2	150	10	0-+	0-+ S	0-+	+ S
3	20	0	0	0	0	0-+
4	20	10	++ M(E)	+++ M(E)	++++ L(E)	+++++ L(E)
5	20	50	++ M(E)	+++ L(E)	+++++ L(E)	+++++ L(E)
6	150	0	0	0-+	0-+	0 +
7	150	10	++ S(E)	+++ S(E)	++++ M(E)	++++ L(E)
8	150	50	+++ M(E)	+++ M(E)	+++++ L(E)	+++++ L(E)
	2) **Stems**		Stem between 3rd and 4th leaf			
1	20	10	+++ S	+++ S		
2	150	10	++++ L(E)	+++++++ L(E)		
3	20	0	+++ S(E)	+++ S(E)		
4	20	10	++++ L(E)	++++ L(E)		
5	20	50	+++++ L(E)	+++++ L(E)		
6	150	0	++++++ L(E)	++++++++ L(E)		
7	150	10	++++++ L(E)	++++++++ L(E)		
8	150	50	++++++ L(E)	++++++++ L(E)		
	3) **Leaves**		Youngset leaf		Next to the youngest	
1	20	10	0-+	0-+	0	0
2	150	10	++++ M(E)	+++++ M(E)	+++ M(E)	+++ L(E)
3	20	0	0-+	0-+	+	+
4	20	10	++ M	++ M	++ M	+++ L(E)
5	20	50	+++ M(E)	++++ L(E)	++	++
6	150	0	++++ L(E)	++++ L(S)	+++++ L(E)	+++++ L(E)
7	150	10	++ S	++ S	+++ L(E)	++++ L(E)
8	150	50	++ S	++ S	+++++ L(E)	+++++ L(E)

Notes : M – Crystals of ammonium molybdic phosphorus are of middle size
(E) – Dense yellow ppt. visible on the slide by the unaided eye
L – Crystals of ammonium molybdic phosphorus are of large size
S – ,, small ,,

These data will be made clearer with respect to the specific traits in rice in comparing them with those in barley which is described in the following page.

(ii) Barley

K. E. Wright[4] reported that the injurious effect of aluminium ion on the plant growth might be attributed to the deficiency of phosphorus which would be caused by its precipitation with aluminium.

From the result of the table 7, it might be considered that the analogous effect as occurred between aluminium and phosphorus might also take place between iron and phosphorus.

In the root inorganically bound phosphorus was not detected simply by high phosphorus application without iron application, but in the stem and leaf it was detected abundantly in this case.

Table 7. Amounts of inorganic phosphorus in the tissues of roots, stems and leaves of the barley plants grown four weeks by the microchemical tests. (Oct. 20, 1949)

Series	Treatment		Immediate	After 3 hours	Immediate	After 3 hours
	P_2O_5	Fe_2O_3				
1) **Roots**			Young root		Old root	
	p.p.m.	p.p.m.				
1	20	10	0	0	0	0-+
2	150	10	++ L	++ L	+ L	+ L
3	20	0	0	0	0	0
4	20	10	++++ L(E)	++++ L(E)	0-+	+
5	20	50	+++ L(E)	+++ L(E)	+++ S(E)	+++ L(E)
6	150	0	0	0	0	0
7	150	10	+++ L(E)	++ L(E)	++ L(E)	+++ L(E)
8	150	50	++++ L(E)	++++ L(E)	++++++ L(E)	++++++ L(E)
2) **Stems**			Stem between 2nd and 3rd leaf			
1	20	10	+ S	+ S		
2	150	10	++++ S(E)	++++++ S(E)		
3	20	0	+++++ M(E)	+++++ L(E)		
4	20	10	+++ M(E)	+++++ M(E)		
5	20	50	0-+	0-+		
6	150	0	++++ L(E)	++++ L(E)		
7	150	10	++++++ L(E)	++++++ L(E)		
8	150	50	+++ L(E)	+++ L(E)		
3) **Leaves**			Youngest leaf		Next to the youngest	
1	20	10	0	0-+	+ S	+ S
2	150	10	+++++ S(E)	+++++ M(E)	++++ L(E)	++++ L(E)
3	20	0	+++ M(E)	+++ L(E)	++ M(E)	+++ L(E)
4	20	10	+ M(E)	+ M	+ M	+ M
5	20	50	+ M(E)	+ M	0-+	0-+
6	150	0	+++++ M(E)	+++++ L(E)	+++++ L(E)	+++++ L(E)
7	150	10	+++ M(E)	+++ M(E)	++++ L(E)	++++ L(E)
8	150	50	++ L(E)	++ L(E)	++++ L(E)	++++ L(E)

Note: Same as the Table 6

Contrary to the above results, when the iron application was increased, inorganic phosphorus was detected abundantly in the root but not in the stem and leaf. Especially in the series 5, a little inorganic phosphorus was found in the stem and leaf, and the yield also was the lowest among all the series. However, in rice, contrary to barley, inorganically bound phosphorus was detected increasingly in both the stem and the leaf with the increase of iron application. This absorptive difference is thought to be the point most carefully noted in the nutritive behavior between rice and barley, and a further discussion will be made on this point in detail in later chapter.

3. Different forms of phosphorus compound in plant body

Water soluble, dilute acid (pH 3) soluble, and residual phosphorus were determined from the dried material of the yielded plant after 30 days' culture.

Ferric phosphate is hardly soluble in water and is the least soluble in dilute acid pH 3 solution as ascertained by many workers[6][7][8]. Therefore it is considered that if there exists ferric phosphate in the plant tissue, it must be included in the residual phosphorus.

For the determination of water soluble PO_4, 1-2 g of the dried material was extracted with 200ml distilled water by shaking it for 30 minutes. Water soluble phosphorus was determined from this filtrate. Insoluble residue remaining after water extraction was again extracted with 200 ml of pH 3 sulfuric acid solution by shaking it for 30 minutes. Dilute acid (pH 3) soluble PO_4 was determined from this filtrate. For the residual phosphorus, insoluble residue remaining after dilute pH 3 acid extraction was ashed in a muffle furnace and phosphorus determination was made

Table 8. Amounts of water-soluble, sulphuric acid solution (pH 3) extracted, residual and total phosphorus in the rice plant. (mg per gram of dry matter)

Series	Treatment			Water sol. PO_4	pH 3 extract. PO_4	Residual PO_4	Total PO_4	Total PO_4 dry wt. of 8 plants
	P_2O_5	Fe_2O_3						
	p.p.m.	p.p.m.						
1	20	10	top	18.48	2.20	3.29	23.97	20.30
			root	8.41	2.61	6.57	17.59	4.78
2	150	10	top	38.49	3.36	4.23	46.08	34.13
			root	15.83	3.74	6.14	25.71	7.02
3	20	0	top	24.54	1.56	4.40	30.50	21.06
			root	8.36	2.11	3.25	13.72	3.31
4	20	10	top	15.06	1.27	5.74	22.07	27.81
			root	8.14	1.82	24.10	34.06	11.01
5	20	50	top	12.32	1.88	5.50	19.70	32.06
			root	2.43	1.69	26.12	30.24	14.72
6	150	0	top	39.38	3.50	5.07	47.95	25.17
			root	16.85	3.88	4.57	25.30	4.63
7	150	10	top	17.44	2.39	4.70	24.30	52.73
			root	15.00	4.60	25.65	45.25	24.31
8	150	50	top	13.35	2.19	4.73	20.27	40.54
			root	10.47	4.86	36.85	52.18	36.89

Table 9. Percentage of water soluble, sulphruic acid extracted and residual phosphorus for the total phosphorus in the rice plant.

Series	Treatment			Water sol. PO_4	pH 3 extract. PO_4	Residual PO_4
	P_2O_5	Fe_2O_3				
	p.p.m.	p.p.m.				
1	20	10	top	77.09	9.18	13.73
			root	47.81	14.83	37.46
2	150	10	top	83.53	7.29	9.18
			root	61.58	14.54	23.88
3	20	0	top	80.46	5.11	14.43
			root	60.93	15.38	23.69
4	20	10	top	68.24	5.75	26.01
			root	23.90	5.34	70.76
5	20	50	top	62.54	9.54	27.92
			root	8.04	5.59	86.37
6	150	0	top	82.13	7.30	10.57
			root	66.60	15.34	18.06
7	150	10	top	71.10	9.74	19.16
			root	33.15	10.17	56.68
8	150	50	top	65.86	10.80	23.34
			root	20.07	9.31	70.62

from this ash. The results of these analyses are shown in Tables 8 and 9 for rice and in Tables 10 and 11 for barley.

(i) Rice

When a comparison of total PO_4 content in the plant was made in the series of varied phosphorus application (series 1, 2, 3, 6,), it was found that the higher the phosphorus application, the larger the total PO_4 in the plant. And the increasing amount of PO_4 caused by the higher application of phosphorus was found to be brought chiefly from water soluble PO_4 and not from the pH 3 acid soluble or residual PO_4.

When the iron application was increased, amount of PO_4 per 1 g per dried sample increased in the root and dec-

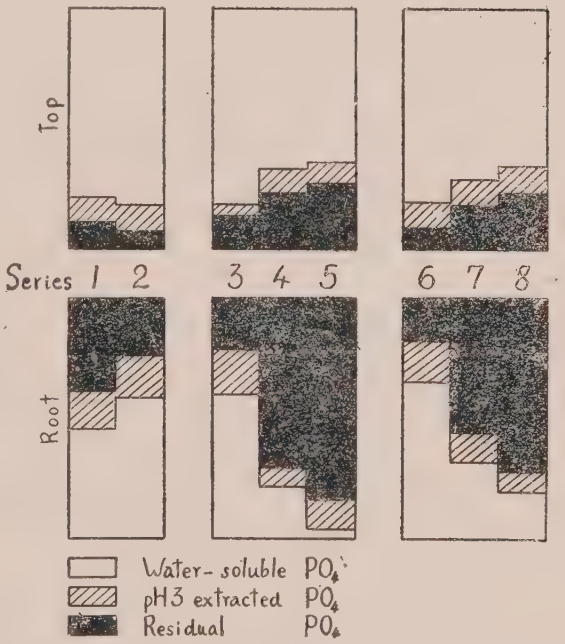


Fig. 1. Percentage of the three fractional phosphorus for the total phosphorus in the rice plant.

reased in top. This variation might have been caused by the fact that the residual PO_4 increased in the root and warer soluble PO_4 decreased in the top. However, judging from the rates of 3 forms of phosphorus as shown in Table 9, it might be said that water soluble PO_4 decreased and residual PO_4 increased with the incrsase

Table 10. Amounts of water-soluble, sulphuric acid solution (pH 3) extracted, residual and total phosphorus in the barley plant. (mg per gram of dry matter)

Series	Treatment			Water sol. PO_4	pH 3 extract. PO_4	Residual PO_4	Total PO_4
	P_2O_5	Fe_2O_3					
	p.p.m.	p.p.m.					
1	20	10	top	14.50	1.78	3.05	19.33
			root	9.60	3.33	4.23	17.16
2	150	10	top	19.35	2.32	4.07	25.74
			root	13.09	2.23	3.53	18.85
3	20	0	top	17.85	2.06	2.84	22.75
			root	10.33	1.49	3.01	14.83
4	20	10	top	14.83	1.69	2.79	19.31
			root	8.43	2.60	13.36	24.39
5	20	50	top	11.39	2.02	3.35	16.79
			root	4.57	1.77	24.23	30.58
6	150	0	top	21.00	3.02	3.14	27.16
			root	21.19	1.72	3.11	26.02
7	150	10	top	16.92	2.70	3.22	22.84
			root	16.50	2.94	15.80	35.24
8	150	50	top	11.26	2.25	3.73	17.24
			root	10.82	1.92	21.89	34.63

Table 11. Percentage of water soluble, sulphuric acid extracted and residual phosphorus for the total phosphorus in the barley plants.

Series	Treatment			Water sol. PO_4	pH 3 extract. PO_4	Residual PO_4
	P_2O_5	Fe_2O_3				
	p.p.m.	p.p.m.				
1	20	10	top	75.01	9.21	15.78
			root	55.94	19.41	24.65
2	150	10	top	75.17	9.01	15.82
			root	69.44	11.83	18.73
3	20	0	top	78.46	9.06	12.48
			root	69.65	10.05	20.30
4	20	10	top	76.80	8.75	14.45
			root	34.56	10.66	54.78
5	20	50	top	67.97	12.05	19.99
			root	14.95	5.79	79.26
6	150	0	top	77.32	11.12	11.56
			root	81.44	6.61	11.95
7	150	10	top	74.08	11.83	14.10
			root	46.82	8.34	44.84
8	150	50	top	65.31	13.05	21.64
			root	31.24	5.55	63.21

of iron supply either in tops or in roots; this tendency was more remarkable especially in the root. These relations can be seen more clearly from the diagram shown in Fig. 1. From the data obtained from these determinations and microchemical test described above, the formation of the iron phosphate in the plant body is considered possible.

(ii) Barley

Tendency of the variation of phosphorus found in the roots and tops in accordance with the amount of application of iron and phosphorus is generally similar to the case of rice. But it was found as the characteristics for barley that the variations as well as the amounts of phosphorus in the tops were small compared with rice (series 1, 2, 3, 6). In this experiment the root seems to play the important role with respect to the absorption of iron and phosphorus although it was not shown so clearly as in the microchemical test.

IV. Discussion

It was shown from the present investigations that the inorganically bound phosphorus increased in the plant body, especially in the roots, with the increasing application of iron in culture solutions as proved by the microchemical test, and furthermore residual phosphorus in which ferric phosphate might probably contain increased with the increase of the iron application. From these experimental results, the combination of iron with phosphorus either in the simple compound or in complex salts, may be formed in the plant body to some extent, and this combination occurrence in the plant may have influence on the physological functions of iron and phosphorus.

It is thought that physiological behaviors of phosphorus and iron in the plant body functionate normally only when their amounts are properly balanced each other.

If their amounts are out of balance either of the two nutrients can not exhibit its physiological functions normally and the plant may be retarded in growth.

According to the foregoing results, marked difference in growth was shown between rice and barley cultured in solutions. This phenomena may be explained by the unbalance produced between iron and phosphorus in the plant which is caused by the different absorbing power of phosphorus and iron between rice and barley as shown by the results of these experiments, namely, in the rice plant, injurious effect caused by high phosphorus application was recovered to some extent by supplying more iron, but contrary to the case of rice, in barley high iron application acted injuriously, probably due to phosphorus deficiency thereby produced. These relations will be explained by the formation of ferric phosphate in the plant body. The rice plant may probably have a weak absorbing power for iron, as it grows in water logged field and utilizes easily absorbable reducing iron from paddy field. On the other hand, barley is thought to have a strong power to absorb iron, as it must absorb with difficulty soluble iron from land field. The rice plant may produce

chlorosis by high phosphorus or low iron application because the active iron is decreased by the formation of ferric phosphate, while barley may produce phosphorus deficiency by low phosphorus or high iron application because phosphorus may be reduced by combining with iron which is absorbed by its strong absorbing power for iron. In short, it may be allowed to say that in rice phosphorus catches the iron, while in barley iron catches phosphorus.

From the results of microchemical tests, when the iron application was increased, inorganically bound phosphate increased in both the roots and the tops in rice, whereas in barley it increased only in the roots and decreased in the tops. This tendency may probably be attributed to the reduced movement of phosphorus due to the precipitation produced by the combination of phosphorus and iron in the roots of barley.

This may further be confirmed also by the fact that the amounts of phosphorus in tops of barley were found far less than in the tops of rice.

Summary

It has been considered that phosphorus induced chlorosis in the rice plant may be caused by the internal precipitation of iron by phosphorus, thus making iron unavailable for its nutrition. In order to ascertain whether iron would be precipitated internally by phosphorus or not, the authors carried out this study fractional chemical analyses and microchemical tests. The seedlings of rice and barley which were grown in the culture solutions with various amounts of phosphorus and iron, were analysed with three fractions, *i. e.*, water soluble, dilute sulfuric acid soluble (pH 3) and residual phosphorus. For the detection of inorganic phosphorus microchemical tests were carried out in the fresh material of these plants.

The results obtained were summarized as follows :

(1) The rice plants grown in culture solutions with higher supplying of phosphorus had an unhealthy appearance, but could be recovered by addition of iron.

(2) Contrary to the case of rice plants higher supply of phosphorus was favorable to the growth of barley plants, while that of iron unfavorable.

(3) According to the results of fractional analyses on the dried materials of rice in the case of higher supplying phosphorus to the rice plant, water soluble phosphorus increased and residual phosphorus decreased. With additional supply of iron, however, water soluble phosphorus decreased and residual phosphorus increased. This tendency was remarkable in the roots of the rice plants and barley plants, but in the tops it was less remarkable in barley than in rice plant.

(4) Results of microchemical tests for inorganic phosphorus in the roots, stems and leaves of these plants after four weeks' culture are as follows :

(i) Rice plants: Increase of inorganic phosphorus by higher supply of phosphorus was seen chiefly in stems and leaves. Inorganic phosphorus also increased in the plant grown with supply of iron, and it was the richest in the tissues of stems.

(ii) Barley: Increase of inorganic phosphorus by higher supply of phosphorus was seen chiefly in stems and leaves. In the case of supply of iron, inorganic phosphorus increased in the roots, but decreased in the stems and leaves.

(5) The results of the present study indicate that the formation of iron phosphate occurs in the tops and roots in rice plants, while in barley plants chiefly in the roots.

Literature cited

(1) J. Kimura, Jour. Agr. Exp. Sta. (in Japanese), **1** (1931), 375.
(2) J. Kimura, Jour. Agr. Exp. Sta. (in Japanese), **2** (1932), 1.
(3) A. Fujiwara, Agr. Hort. (in Japanese), **23** (1948), 331.
(4) K. E. Wright, Plant Physiol., **20** (1945), 310.
(5) G. Klein, Planta, **2** (1926), 497.
(6) S. Osugi, S. Yoshie and N. Nishigaki, Jour. Agr. Chem. Soc. Japan, **8** (1932), 280.
(7) R. M. Swenson, C. V. Cole and D. H. Sieling, Soil Sci., **67** (1949), 3.
(8) K.E. Wright, Plant Physiol., **18** (1943), 708.

On the New Method of Inoculation on Rice Plants with the Blast Fungus, *Piricularia oryzae* Cav.*

Masayuki Sakamoto

(Received Oct. 10th, 1949)

In case of a fundamental investigation in biology it is common to prefer such material as will be suitable for performing the investigation. For example, Chlorella is used for the study of photosynthesis, and fresh water algae, such as Nitella, Chara, and Valonia, for permeability ; and some of those became standard materials for investigation. In applied sciences, on the other hand, projects for investigation are originally given and one is not allowed to apply any desired material which would be convenient for experiment or observation. Although in studying fundamental problems in plant pathology a desired material can be applicable, we must bear in mind the economic importance of the disease in question. Thus, fair restrictions are, of course, being put upon the experimental techniques in our field of research. Under this status utmost efforts must be made in order to promote study.

It may be said that all pathological phenomena are in general induced by the host-parasite reactions, so that researches in this field must be performed based on this relation. This is actually realized only by the inoculation, which is an important starting-point of investigation. Plant pathologists usually adopt such an inoculation method, in which a pathogene is applied on host plants and after a certain period results are examined with naked eyes. This is enogh to tell the differences in virulence of certain pathogenes or resistance among various host plants. When lesions do not appear, however, this method cannot tell clearly, whether the pathogene can not enter into host-tissue or if its action is stopped after invasion. This alternative can be decided only by histopathological observation.

So far in this case we depend only upon the microscopic observations on fixed preparations. This is a reliable method, however, it needs too much time and labour for making up preparations. So it sometimes lacks elasticity and efficiency in order to change its experimental conditions or procedures successively by examining the foregoing experimental results. In some cases vital observations also

* The 26th report of the Institute for Agricultural Research, Tohoku University. (1951)

became necessary.

In the course of study on blast disease of rice plant, the writer found that the inner epidermal tissue of a sheath of rice plant can be a more or less suitable material for the above mentioned conditions and for vital observations of various reactions which occurred in affected host-cells or of the behaviour of a invaded pathogene. Some authors have published reports concerning results obtained by the present method, and the writer sometimes received a personal communication of them. I hope that the following outline of the method will be of some help to them and the writer is ready to face frank criticism by them.

Structure of leaf-sheath of rice plant

A leaf of rice plant, as in other graminaceous plants, is composed of a leaf-blade and -sheath. The base of the latter develops from the node and wraps a culm. At the joint of the sheath and blade there is a ring-shaped node which has ligule and hair. It is most thick at the central part (midrib), becoming thinner towards the rims, and curves inside, wrapping the culm. The inner tissue consists mainly of parenchyma and vascular boundles (Pl. I, 1).

The structure of the outer part of a sheath is similar to that of the undersurface of a blade, which has an assimilating tissue and a well-developed mechanical tissue (stereom). On the contrary the inner part of a sheath, on which the pathogene is to be inoculated, has not those tissues. Seen from above, epidermal cells show nearly a rectangular form, and their contents are optically empty and homogeneous, including non remarkable microsomes (Pl. I, 2–6). Nucleus is visible almost at the central part of a cell. Subepidermal cells become wider and shorter downwards, and at the third or fourth layer their cross sections appear nearly square. There are also stomatal cells on epidermis. The cells, which consist of a part connecting with a vein of leaf-blade, are narrow and long in shape, arranged in a row and can be easily distinguished from ordinary epidermal cells. The silication of epidermal cells inside of a sheath occurs in general very rarely.

Method of inoculation

A culm of rice plant is cut off from its base and the sheath part is cut further in a proper length (7–10 cm). The culm is removed carefully with a firm pincette ; in this procedure one must be careful not to crush or scratch the sheath-tissue. It may be better to put the cut sheath in water beforehand in order to increase the turgidity of the tissue. The empty sheath is then carefully filled with a diluted spore suspension by using a pipette or syringe, and placed in moist chamber in an incubator. After a certain period the sheath is taken up and the discoloured ends are cut off. Then the epidermal layer (two- or three-cell thick) is stripped with a razor and examined microscopically.

In order to hold the inoculated sheaths firmly during the incubation the follow-

ing devices are made : Two long pieces of hard paper, being folded longitudinally and cut in a serriform at the fold, are arranged in parallel on a wet filter-paper set in a Petri dish, and on them the inoculated sheaths are placed. The hard paper is previously applied with paraffin. Care must be taken that the suspension may not flow out by shaking or slanting the sheath.

The concentration of a spore suspension should be more diluted than that in an ordinary inoculation experiment. Otherwise, the lesions developed from severa neighbouring spores may be entangled with each other ; and an observation may become very difficult and the host-parasite reactions will be influenced unfavourably. If bacteria are contaminated in a spore suspension, the action of pathogene will be impeded and it becomes, of course, unfavourable for observation, so that such a case must be avoided.

Although it is desirable to make vital observation in general, a proper fixing reagent will be applicable, when many materials are to be examined. In this case strong dehydrative reagent is not recommended.

In order to make a vital observation continuously on the behaviour of invaded pathogene or the pathological changes in host-cells, it is necessary to insert small pieces of cover slip or capillary tubes between cover and slide glasses and sometimes to supply them with fresh water. After all, stripped tissues or cut leaf-sheaths are not appropriate for long-time observation. In this case it is desirable to apply intact preparations. Sheath is slightly drawn off from a culm with care, and then the space between them is filled with spore suspension or inserted with absorbent cotton soaked in spore suspension. The inoculated plants are placed in moist chamber. This method needs too much labour for detecting an invasion case which is suitable for observation. But it is a merit of the method that experiment can be made under natural conditions of plants.

Thus the present method is simple to perform in its procedure. Several examples obtained by this method will be shown in the following chapter.

Experiment

The invasion of pathogene into host-tissue and its spreading process will be illustrated first of all. The conidiospores in suspension sink and settle on epidermal layer. They germinate after 2–5 hours and form appressoria after 6–15 hours. Contents of spore remove into the appressorium. In 12–20 hours a slender infection hyphae emerges from the underpart of appressorium and invades into a host cell through epidermal wall. (Pl. I, 2) It begins to swell again and the contents of appressorium remove into this part. Thus the invasion has been accomplished. After 40–50 hours the pathogene affects several epidermal cells, in some cases over ten cells, and spreads into subepidermal layer simultaneously.

The above is the invasion process which is observed in susceptible plants or nitrogen-excess plants. Pathological changes which occur in affected host-cells

can usually be seen a fairly long time after the invasion. On the other hand, in resistant or nitrogen-shortage plants the changes occur sooner and the further development of pathogene is stopped.

Table 1 shows results of an application of the present method for rice plant varieties of different resistances. *Shinriki* and *Norin No. 1* as susceptible varieties, *Kameji* and *Futaba* as resistant ones and *Norin No. 16* as a medium resistant one were used. The temperature during the incubation period was about 24°–28°C. After 48 hours' incubation the stripped tissues were fixed by dilute alcohol and then examined.

Table 1. Result of the observations on the mycelial growth in sheath-tissues of different rice varieties.

Variety	Number of cells, invaded	Degree of mycelial growth in invaded host-cell					Total
		(±)	±	+	++	+++	
Shinriki (susceptible)	0	46	37	8	0	1	92
	1— 2	0	21	8	0	1	30
	3— 4	0	20	30	9	2	61
	5—10	0	15	36	44	22	117
	11—20	0	1	14	27	32	74
	>21	0	0	0	5	22	27
	total	46	94	96	85	80	401
Norin No. 1 (susceptible)	0	36	56	0	0	0	92
	1— 2	0	34	10	1	0	45
	3— 4	0	30	21	5	0	56
	5—10	0	15	73	48	9	145
	11—20	0	0	12	49	34	95
	>21	0	0	0	3	6	9
	total	36	135	116	106	49	442
Norin No. 16 (resistant)	0	197	58	3	0	0	258
	1— 2	0	43	3	0	0	46
	3— 4	0	23	12	3	0	38
	5—10	0	7	21	7	0	35
	11—20	0	0	0	0	0	0
	>21	0	0	0	0	0	0
	total	197	131	39	10	0	380
Kameji (resistant)	0	172	75	2	0	0	249
	1— 2	0	44	11	1	0	56
	3— 4	0	14	20	5	0	39
	5—10	0	1	3	4	0	8
	11—20	0	0	0	0	0	0
	>21	0	0	0	0	0	0
	total	172	134	36	10	0	352
Futaba (very resistant)	0	186	20	0	0	0	206
	1— 2	0	6	0	0	0	6
	3— 4	0	1	0	0	0	1
	5—10	0	0	0	0	0	0
	11—20	0	0	0	0	0	0
	>21	0	0	0	0	0	0
	total	186	27	0	0	0	213

According to the above table, the differences in number of invaded cells and degree of mycelial growth in affected host-cells among varieties are clearly seen according to their different resistances.

Furthermore, interesting phenomena can be seen by this method when various treatments are given on leaf-sheath before inoculation or just after the invasion of a pathogene into host-cell. Table 2 shows results of the observation on the mycelial growth in sheath-tissue by a pretreatment with dilute ammonia solution. *Bozu No. 5* variety (rather susceptible) was used in this experiment. A sheath was cut in two lengthwise ; a half was treated with dilute ammonia solution (N/500) during 6 hours (24°C) and the other treated with distilled water under the same conditions for the purpose of comparing. The microscopic observation was carried out after 42 hours' incubation (24°C).

Table 2. Effect of the pretreatment by dil. HN_4OH solution (N/500) upon mycelial growth in sheath-tissues.

Pretreat.	Number of cells, invaded	Degree of mycelial growth in invaded host-cell				Total
		±	+	++	+++	
Dist. water (control)	0	134	62	27	3	226
	1— 2	0	0	8	5	13
	3— 5	0	0	1	1	2
	6—10	0	0	0	0	0
	>11	0	0	0	0	0
	total	134	62	36	9	241
Dil. NH_4OH solution	0	164	53	0	0	217
	1— 2	11	28	33	14	86
	3— 5	1	12	17	15	45
	6—10	0	0	5	5	10
	>11	0	0	1	0	1
	total	176	93	56	34	359

Evaluation of observation results

Y. TAKAHASHI[3] classified the degree of hyphal developments in affected host-cells into 5 value-classes, *viz.*, 0.5, 1, 2, 3, and 4, and calculated the infection grade (v) according to the following formula :

$$v = \frac{\Sigma df}{n},$$

where d indicates the class value shown by each appressorium ; f is an individual number which belongs to each class ; and n is the total number of appressoria except in the case of 0, *viz.*, the case in which no invasion can be observed.

Y. TAKAHASHI calculated the infection degree on leaf-sheath of F_1 plants which were obtained by crossing among various varieties of rice plants and tried a gene analysis in relation to the heredity of resistant chatacter against the blast disease

by the analysis of variance based on these numerical values.

As the writer is now engaged in researches on the nature of the blast-disease resistance in rice plant, he did not yet get an opportunity to examine the propriety of this clculation of infection grade advocated by TAKAHASHI. I wish for criticisms, by those, who made observations by the present inoculation method, since it is very important to get an adequate numerical value as an evaluation of virulence or resistance.

Evaluation of the new method

It is necessary in general to know the advatageous and the disadvantageous points of any experimental method which is to be adopted. As already mentioned above, the excellence of a sheath-inoculation method presents in the following points : Only after 2 days' incubation results can be obtained ; during a short period various observations are possible ; experimental technique is very simple ; and furthermore, it is possible to investigate an host-parasite reaction *in vivo*. The present method is also applicable in case of the mature plants which will be no more infected with a spore spray method.

It is said that there are sometimes differences between the leaf- and neck-blast resistance in the same variety. Possible differences in resistance between blade- and sheath-tissues may present, since they are different in their morphological characters as well as in contents of certain nitrogenous compounds as will be mentioned later. However, according to the writer's observations and also Y. TAKAHASHI's, the above mentioned discrepancy between both tissues on resistant grade could not be confirmed.

Table 3 shows the different contents of certain nitrogenous compounds between leaf-blades and -sheaths.

Table 3. The different contents of certain nitrogenous compounds between leaf-blades and -sheaths of rice plant (N mg per 1 g of green weight), and their percentages to total N. (Var. : *Hatsumurasaki*)

	Total N	Protein-N	Soluble N	NH_3-N	Amide-N	Rest-N
Blade	12.2094	10.8886	1.3258	0.0336	0.0658	1.2264
	100	89.14	10.86	0.28	0.54	10.04
Sheath	3.8332	2.3492	1.4840	0.0364	0.0742	1.3734
	100	61.29	38.71	0.95	1.94	35.83

As shown in Table 3, the contents of nitrogenous compounds in leaf-sheaths are far less than those in leaf-blades, and especially the percentage of protein-nitrogen to total nitrogen is fairly low. A remarkable difference can also be observed in their soluble N contents. So it is possible that the above mentioned differences between both tissues have at least quantitative influence upon the host-parasite reactions.

It must be noted here that a tissue removed from its mother palnt can not hold its normal condition for a long period, because autolysis always occurs. Table 4 shows the analytical data which mean the changes in various nitrogenous compounds in leaf-sheaths during incubation. A sheath was cut lengthwise ; a half was analysed immediately and the other was analysed after 48 hours' incubation in a dark incubator at 22°–24°C.

Table 4. The protein degeneration in sheath-tissue during 2 days' incubation (22°-24°C) in a dark incubator (N mg per 1 g of green weight), and their percentages to total N. (Var. : *Bozu No. 5*)

	Total N	Protein-N	Soluble N	NH_3-N	Amide-N	Rest-N
Before incubation	2.9316 100	2.2330 76.17	0.6986 23.83	0.0392 1.34	0.1400 4.78	0.5194 17.72
After incubation	2.5074 100	1.7038 67.95	0.8036 32.05	0.0560 2.23	0.1764 7.04	0.5712 22.78

The leaf-sheath showed somewhat faded green and lost its turgidity more or less after 48 hours. As shown in Table 4 protein degeneration occurred and an increase of soluble nitrogen was observed. In other experiments the protein degeneration did not occur hardly within 24 hours. But since autolysis occurs rapidly, it is unfavourable to continue the experiment with cut tissue over 2 days' duration. Protein degeneration increases at higher temperatures, and considering temperature requirements of the pathogene the incubation at 22°–25°C will be the most suitable condition. The process of protein degeneration can be retarded by the presoaking of a sheath-tissue in dilute sugar solution, but in this case the influence of the sugar upon the growth of a pathogene in host-tissue is clearly observed. The use of intact sheath-material will, therefore, be desirable. However, materials for experiment must be decided according to their purpose, and it is also a good way to apply various methods jointly.

The invasion processes of the blast fungus in sheath-tissues as well as in blade-tissues clearly show differences according to their ages and parts even within the same sheath ; it is necessary to pay attention to these factors for performing experiment.

It is worthy here to take note on blast fungus as a inoculum. Condiospores, which elapsed so many days after formation, should be avoided to use for inoculation experiment, because they show lower virulence than those freshly formed. It must also be kept in mind that the cultural conditions of the pathogene to be used as inoculum will have a marked influence upon its virulence. Successful results could be obtained in many cases by using condiospores, which had been formed freshly on lesions of susceptible plants. In this case also the changes of virulence due to different nutritive conditions or varietal resistances of host-plants must be taken

into consideration, as was pointed out by some authors.[1,2,4]

Thes heath inoculation method is applicable also in the investigation of various diseases of graminaceous plants other than rice plants.

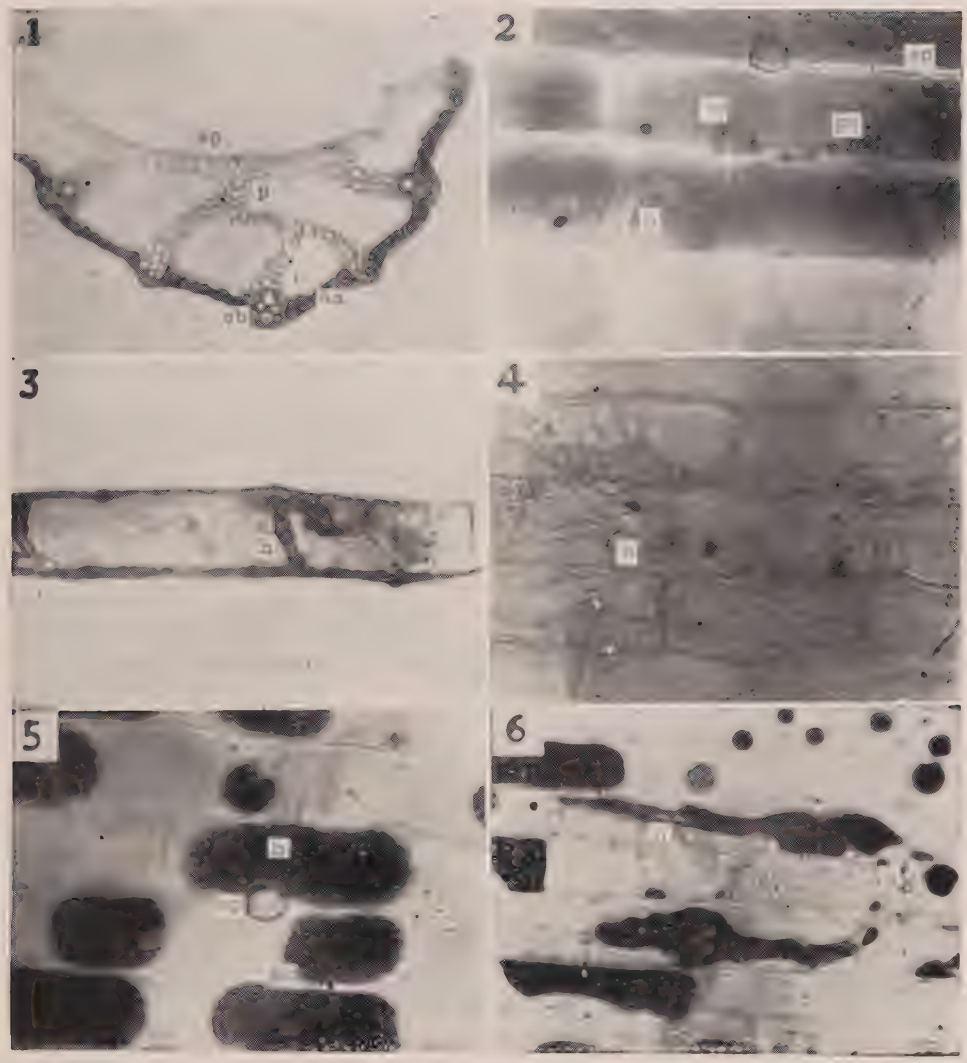
Summary

The writer devised a new convenient method for inoculation using a leaf-sheath of rice plant. After only 2 days' incubation results could be obtained. The procedures for inoculation and making up preparations are very simple. The present method is applicable to the investigations on various disease of graminaceous plants.

Experimental conditions to be taken care for carrying out investigation were also noted.

References

(1) Hemmi, T., Abe, T., and R. Takahashi, Annual report on the blast disease of rice plant, sent to the Ministry of Agriculture for the year 1941.
(2) Takahashi, Y., Agr. Sci. of The North Temperate Region, **1** (1947), 201.
(3) ———————, Ann. Meet. of The Phytopath. Soc. Jap. for the year 1949, and private communication.
(4) ———————, Ann. Phytopath. Soc. Jap., **13** (1948), 19.
(5) Tochinai, Y., and Hara, I., Med. and Biol., **1** (1942) 134.



1. Photomicrograph of the cross section of a midrib of sheath (*Norin No. 1*, susceptible variety) : ×50. p, parenchyma ; ep, inner epidermal layer, on which the fungus is inoculated ; as, assimilation tissue ; vb, vasular bundle.

2–6. Photomicrographs of the inner epidermis of a sheath infected by the blast fungus. ×800. sp, conidiospore ; gm, germ tube ; ap, appressorium ; h, hyphae developed in host-cell.

2. 24 hours after inoculation (*Hatsumurasaki*, rather susceptible variety).

3–4. 50 hours after inoculation (*Bozu No. 5*, a medium resistant variety). 3. Nitrogen shortage plant ; 4. Fully fertilized plant.

5–6. Plasmolysis in 0.8 ml sucrose solution (*Hatsumurasaki*). 5. 24 hours after inoculation , 6. 50 hours after inoculation.

Studies on the Grassland Type and the Plant Succession of Bokuya (Natural Grassland) in Japan*

Shigeharu Yoshida

(Received September 9, 1950)

I. Introduction

Knowledges on the process of plant succession in Bokuya (natural grassland including 3 types such as grazing land, meadow land and their combined type) certainly from the basis of measures for maintenance and improvement of the vegetation in Bokuya. In recent years researches for the plant succession in Bokuya have been carried out to an insufficient degree. However the work by Moto-o Ōseko[1] must be noted here. He made great efforts to systematize the process of plant succession in Bokuya. He explained the results obtained by researches in Bokuya attached to the Forest Experimental Station as follows : (see Fig. 1)

After the forest climax stage has been extinguished by biotic disturbances, grassland of *Miscanthus* stage can be observed. This grassland, however, will be changed according to biotic disturbances by grazing, mowing, burning, etc. into *Imperata* stage grassland, which then becomes *Zoysia* stage grasslands by acute disturbances. And it finally becomes waste stage grassland which has already lost the value of Bokuya.

During my researches in Bokuya since 1936 in 50 places throughout Japan (23 places in Tohoku District, 6 in Kanto- and Shin-etsu District, 2 in Kinki District, 4 in Chugoku District, 3 in Shikoku District and 12 in Kyushu District), the results obtained differed remarkably from those by Ōseko. Namely that which corresponds to *Imperata stage* among the 4 stages of vegetation concluded by Ōseko has not been observed.

In order to consider the plant succession in Bokuya, which is detailed in the following chapters, I classified the vegetation of the investigated places into various grassland types. As in Bokuya acute biotic disturbances have been observed, the types of grasslands are comparatively simple and can be divided into a few categories only. The plant succession of these kinds of grassland types will be respective-

* The 54th report of the Institute for Agricultural Research, Tohoku University. (1951)

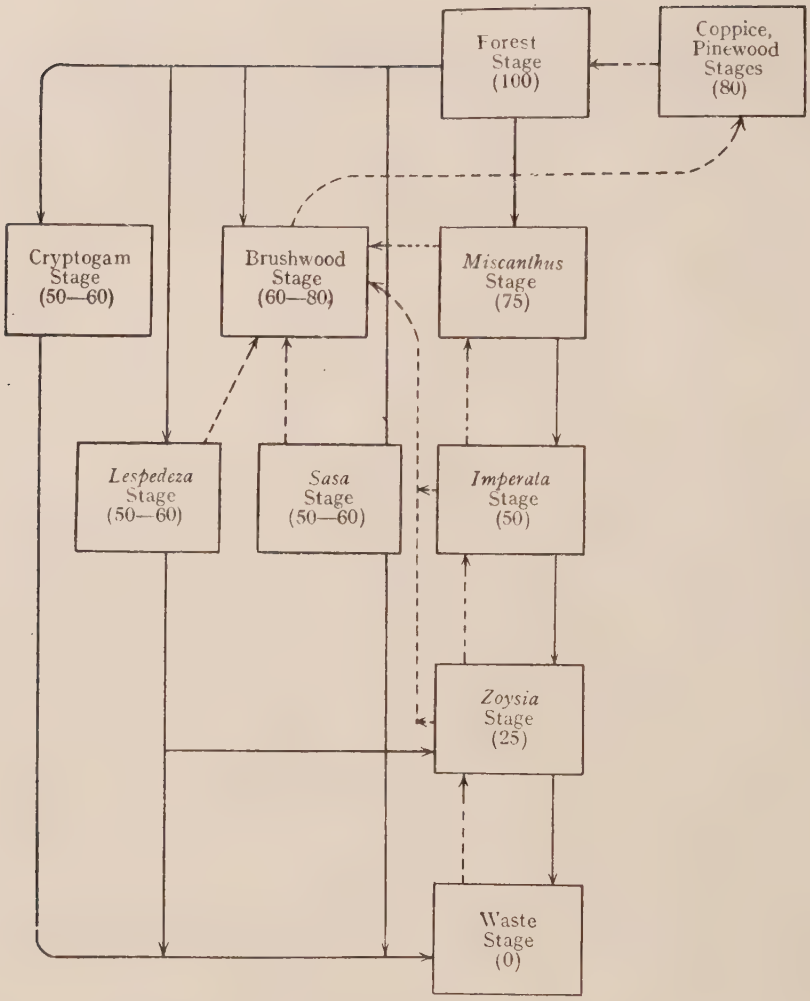


Fig. 1. Grass type, plant succession and soil fertility.
(by M. Oseko)

Note: Parenthesized figures represent the fertility of each stage soil.

ly investigated individually in the future. A remarkable improvement of the vegetation in Bokuya can be explected from it. The author hopes that the present paper will contribute in some degree to the research in this field.

II. Methods

The Bokuya which have been investigated since 1936 amount to circa 10,000 hectares in area. As I was allowed only a limited time to investigate in detail the plants in these Bokuya, I was obliged to depend upon the belt transect method and

dealed only with the main constitutional grasses of grasslands, omitting the grasses, which appeared infrequently. Beforehand simple preliminary studies were carried out in order to avoid any mistake. Although from the ecological standpoint the above mentioned method is not always perfect, the author believes that dominant species and grasses with secondary cover degree and frequency as well as cosmopolitic species can be investigated sufficiently.

And still more grasses widely distributed in this country such as *Miscanthus sinensis* Anderss., *Imperata cylindrica* Beauv. var. *Koenigii* Durand et Shinz., *Zoysia japonica* Steud., *Sasa* spp.* *Lespedeza* spp.** and *Pteridium aquilinum* Kuhn, var. *japonicum* Nakai which are elemental grasses for the plant succession of vegetation in Bokuya, were much carefully observed.

III. Results

1. Grassland Types of Bokuya

Table 1 shows classified grassland types according to the researches on vege-

Table 1. Grassland types of Bokuya in Japan.

Grassland type	Number of grassland	% to total grassland number of each stage	% to total grassland number
Miscanthus stage grassland		%	%
Miscanthus type	17	50.0	22.3
M. — Sasa type	5	14.7	6.6
M. — Lespedeza type	4	11.8	5.3
M. — Pteridium type	3	8.8	3.9
M. — Zoysia type	4	11.8	5.3
M. — Artemisia type	1	2.9	1.3
Total	34	100.0	44.7
Zoysia stage grassland			
Zoysia type	11	45.8	14.5
Z. — Pteridium type	6	25.0	8.0
Z. — Miscanthus type	4	16.7	5.3
Z. — Rhododendron type	2	8.3	2.6
Z. — Trifolium type	1	4.2	1.3
Total	24	100.0	31.6
Sasa stage grassland			
Sasa type	11	78.6	14.5
S. — Miscanthus type	3	21.4	3.9
Total	14		18.4
Pteridium stage grassland			
Pteridium — Zoysia type	2	50.0	2.6
P. — Lespedeza type	2	50.0	2.6
Total	4	100.0	5.3
Total	4		100.0

* *Sasa albomarginata, S. nipponica, S. paniculata,* etc.

** *Lespedeza vicolor* var. *japonica, L. cyrtobotrya, L. sericea,* etc.

tation in 76 grasslands in 50 places of Bokuya. Only 4 sorts of grasses could be observed as dominant species in Bokuya, viz. *Miscanthus sinensis, Zoysia japonica, Sasa* spp. and *Pteridium aquilinum* var. *japonica.* Therefore, I divided grasslands into main classes of *Miscanthus* stage, *Zoysia* stage, *Sasa* stage and *Pteridium* stage. The term stage has been added upon the supposition, that climax stages of these grasslands would be existent. However, these four types are not always in their climax stages, and the others can show the cover degree and the frequency near to the above mentioned, so that these stages were further classified. For example *Miscanthus* stage grassland was classified into *Miscanthus-Sasa* type, *M.-Zoysia* type, etc. However, in the case that *Miscanthus*, for instance, is overwhelmingly dominant, it is called merely *Miscanthus* type, and this is the very grassland in the climax stage of *Miscanthus.*

This classification is not a special project, but that method, which is usually adopted in order to classify the associaton in the plant ecology. It must be, however, noted here that numbers of the species classified are small and limited. Namely this classification deals only with 8 sorts, *i.e.* grasses as *Miscanthus, Zoysia,*

Table 2. Grassland types of Bokuya in Japan. (depend on reference data)

Grassland type	Number of grasslands	% to total grassland number of each stage	% to total grassland number
Miscanthus stage grassland		%	%
Miscanthus type	128	47.6	37.1
M. — Sasa type	3	1.1	0.8
M. — Pteridium type	130	48.3	37.7
M. — Zoysia type	1	0.4	0.3
M. — Artemisia type	1	0.4	0.3
M. — Agrimonia type	1	0.4	0.3
M. — Potentilla type	2	0.7	0.6
M. — Phragmites type	1	0.4	0.3
M. — Disporum type	1	0.4	0.3
M. — Hierochloe type	1	0.4	0.3
Total	269	100.0	78.0
Zoysia stage grassland			
Zoysia type	15	20.8	4.3
Z. — Miscanthus type	54	75.0	15.6
Z. — Plantago type	1	1.4	0.3
Z. — Sanguisorba type	1	1.4	0.3
Z. — Carex type	1	1.4	0.3
Total	72	100.0	20.8
Sasa stage grassland			
Sasa — Zoysia type	2	50.0	0.6
S. — Miscanthus type	1	25.0	0.3
S. — Peteridium	1	25.0	0.3
Toatl	4	100.0	1.2
Total	345		100.0

Sasa, Pteridium, Artemisia, Trifolium repens* and brushs as *Lespedeza* and *Rhododendron,*** so that the types classified are small in number and very simplified.

To make sure of this, the classification of the reference data on 345 grasslands in 23 literatures by the same method (Table 2) indicates that the elementary grasses, classified in stage, are also *Miscanthus, Zoysia* and *Sasa,* and the grasses classified in type respectively are *Pteridium, Artemisia, Agrimonia japonica, Potentilla, Freyniana, Phragmites longivalvis, Disporum smilacinum, Anthoxanthus japonicum, Plantago major* var. *asiatica* and *Sanguisorba officinalis* besides the above mentioned 3 grasses. It is, therefore, limited to 12 kinds of grasses in all.

Now let us consider, which type would show in this country the greatest frequency among those which are composed by these 8 or 12 kinds of grasses.

(i) *Miscanthus* stage grassland

This stage grassland is of the greatest importance in Japan.

There are 6 types, which belong to this stage. They are seen in 34 grasslands—44.7%—out of 76, which are grasslands in 50 Bokuya throughout Japan (according to the reference data in 269 grassland out of 345—78%***. And among the grassland types of this stage the *Miscanthus* type in which *Miscanthus sinensis* Anderss. is overwhelmingly dominant, shows the greatest percentage of 22,3% (37.1%), so that we can observe the not so low utilizing value of Bokuya in this country. However, if this stage is the first appearance as grassland, it can be assumed that the percentage of this stage is at present lower. Because the total percentage of this stage is only 44.7% and *M.-Sasa* type and *M.-Lespedeza* type would be better but *M.-Pteridium* type or *M.-Artemisia* type, in which *Pteridium* and *Artemisia* unesculent for live-stock grow up, as respectively 3.9% (37.7%—remarkably high percentage) 1.3% (0.3%), and still more, *Miscanthus-Zoysia* type, into which *Zoysia* of lower productivity has been mixed, is 5.3% (0.3%). The appearance of these 3 types in this stage indicates that the value of Bokuya has been fairly degenerated. It is, therefore, an urgent necessity to maintain as much as possible this *Miscanthus* stage grasslamd, which can show the highest productivity.

In Table 2 there are the other types which show lower frequency and can be regarded as particular cases. Many of these contain grasses inedible for live-stock. It will be possible that in these types only unvaluable grasses would remain to the future and they would be turned into the so-called "weedy type" one of the waste stage grassland of lower productivity.

(ii) *Zoysia* stage grassland

Under the best condition the length of *Zoysia japonica* can be less than 10cm. Thus the grassland of this stage shows the lowest productivity. It is noteworthy for the policy of Bokuya that this grassland shows the frequency of 31.6% (4.3%).

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* chiefly *A. japonica* and *A. vulgaris.*

** *R. japonicum, R. obtusum* var. *Kempferi,* etc.

*** Parenthesized figures in this paper represent those according to the reference data.

Also the fact that there are some regions as sights, where shrubs such as *Rhododendron* spp. grow up actively and that *Z.-Pteridium* type indicates 8.0% is a matter of deep concern for the management of Bokuya.

However, *Zoysia-Miscanthus* type indicates 5.3% (15.5%), and it can be assumed that grassland of *Zoysia* type would be changed by following into *Zoysia-Miscanthus* type and then into *Miscanthus-Zoysia* type, so that it will not be impossible to improve the grassland at this stage successfully.[3] And the appearance of *Zoysia-Trifolium* type attributed to the bringing of *Trifolium repens* seeds by live-stock. Under the good management this type shows active growth and can overcome *Zoysia* at last. In this case also the invasion of other valuable grasses can be observed, however, it will admit of no improvement, when the overgrazing is continued.

In the *Zoysia* stage although partially, it can occasionally be seen in such grasslands of the *Zoysia-Plantago** and *Zoysia-Sanguisorba*** type, which have been caused by the disturbance of overgrazing. In some extreme cases it becomes bare grass grassland. As remarkable cases, there is such a Bokuya, which is 13 km far from the seashore but has been invaded by *Rosa rugosa*. It can be said, that these grasslands are already in the so-called "waste stage".

It must be noted here that although the main constitutionl grasses in Japan are small in number and limited, in *Miscanthus* stage grasslands there are besides the elemental grasses above mentioned many valuable accompanied grasses such as *Spodiopogon cotulifer*, *Spodiopogon sibiricus*, *Arundinella anomala* and the others which belong to Graminae. However, in *Zoysia* stage these grasses have disappeared entirely or decreased extremely, so that the utilizing value of Bokuya becomes lower and very simple, and the frequency of unvaluable grasses shows a remarkable increase (Table 3).

The fact that Bokuya in this stage have degenerated qualitatively as well as quantitatively, is a matter of interest not only for the investgation of plant succession, but also for the practical management of Bokuya.

(iii) *Sasa* stage grassland

Grasslands of *Sasa* stage are of the greatest importance as well as the *Miscanthus* stage grassland and widely distributed in Japan and one of those, can be seen after forests and brushs have been felled. It shows 18.4% (1.8%) which will be higher ,if Bokuya in Hokkaido would be added.

The types, which belong to this stage, are comparatively small in number, viz. *Sasa* type—14.5%—and *Sasa-Miscanthus* type—3.9% (according to the reference data 3 types, viz. *Sasa-Miscanthus* type—0.6%—and *Sasa-Pteridium* type—0.3%). This is attributed to the ecological character of *Sasa* spp. *Sasa* grassland is thus very simplified, but *Sasa* is a good forage plant and especially it is of vast value in winter, when all other grasses are withered but only this offers green

* *Plantago major*
** *Sanguisorba officinalis*

Table 3. Names of the main accompanied grasses in each grassland stage.

Grassland stage	Names of grasses
Miscanthus stage	*Spodiopogon sibiricus Trin.* *S. cotulifer Hack.* *Themeda triandra Forsk. var. japonica Makino* *Arundinella anomala Steud.* *Calamagrostis arundinacea Roth. var. sciuroides Hack.* *C. sachalinensis Fr. Schn.* *C. Epigeios Roth.* *Koeleria cristata Pers.* *Zoysia japonica Steud.* *Lespedeza vicolor Turcz. var. japonica Nakai.* *L. cyrtobotrya Miq.* *L. sericea Miq .....etc.* *Pteridium aquilinum Kuhn var. japonicum Nakai.* *Sasa albo-marginata Makino et Shibata.* *Sasa albo-marginate Makino et Shibata.* *S. nipponica Makino et Shibata* *S. paniculata Makino et Shibaa .....etc.* *Pueraria hirsuta Matsum.* *Artemisia japonica Thunb.*
Zoysia stage	*Pteridium aquilinum Kuhn var. japonicum Nakai* *Hydrocotyle Wilfordi Maxim.* *Convallaria majalis L.* *Rosa rugosa Thunb.* *Polygonum Reynoutria Makino* *Agrimonia japonica Koidz.* *Ranunculus japonicus Langsd.* *Viola spp.* *Sanguisorba officinalis L.* *Cirsium spp.* *Lespedza spp.* *Spodiopogon sibiricus Trin.* *Miscanthus sinenis Anderss.* *Arnudinella anomala Steud.* *Duchesnea indica Focke* *Rubus spp.* *Artemisia japonica Thunb.* *Lotus corniculatus L. var. japonicus Regel* *Plantago major L. var. asiatica Decne.* *Rumex acetosella L.*
Sasa stage	*Miscanthus sinensis Anderss.* *Arundinella anomala Steud.* *Spodiopogon sibiricus Trin.* *S. coturifer Hack.* *Lespedeza spp.* *Pteridium aquilinum Kuhn var. japonicum Nakai* *Cartex lanceolata Boott.*
Pteridium stage	*Zoysia japonica Steud.* *Hydrocotyle Wilfordi Maxim.* *Anemone cernua Thunb.* *Ranunculus japonicus Langsd.* *Lespedeza spp.*

leaves. As its nature is weaker than one may think, a special care is necessary in the sprouting season of spring and the maximum growing season in summer.[6] If, however, the grassland of this type is utilized only in winter, it will be continued for a long time.

(iv) *Pteridium* stage grassland

Pteridium aquilinum is not edible for live-stock and of a very strong nature,

so that it is widely distributed in Bokuya and can exist, even if disturbed biotically such as by burning and crushing by grazing. At present this stage shows only 5.3% ; 2 types. *i.e.*, *Pteridium-Zoysia* type-2.6% and *Pteridium-Lespedeza* type—2.6%, are seen in this stage. It is, however, assumed that in the future this stage will indicate a remarkable increase.

The appearance of each grassland type in this stage is due to overgrazing and burning, by which *Pteridium* spp. and *Lespedeza* spp. inedible for livestock will remain (Although *Lespedeza* spp. is a good forage plant, its green leaves contain tannin before florescence, so that they are not eaten by any livestock except goat. *Lespedeza* spp. is, therefore, mown and used as dried forage in winter). There is a great possibility that in the near future grasslands of *Pteridium-Zoysia* type will appear on a great scale. The contents of grasses in this stage are very simple as well as in *Zoysia* stage. In other words, there can be, except in the case of *Lespedeza* picking field, scarcely any utilizing value of Bokuya in this stage, which has reached to a waste stage.

As the sorts of main constitutional grasses in Bokuya are very small in number and limited ; the types which are classified by these sorts of grasses, are also small in number. And biotic disturbances such as overgrazing and burning of these grasslands decrease the number of valuable grasses, which are component elements in these grasslands, and these become very simple from the standpoint of the utilization of Bokuya and lose nearly all their value.

It is a matter of course that all the Bokuya do not always belong to these limited types, but there can be differences according to the age of Bokuya, the method of management, the productivity of soil and other environmental conditions. But in proportion to the historical age of Bokuya its vegetation has been simplified and this is caused chiefly by overgrazing and burning, which are customary managements of Bokuya in Japan. And moreover, it is a noticeable fact that the results brought by these customary managements are not only a simplification of its vegetation, but also a rapid and acute succession of vegetation.

If in the future the plant succession of each grassland type would be respectively observed, the management suitable for each Bokuya could be performed with comparative case.

2. Plant Succession of Vegetation in Bokuya

It is impossible to detail the plant succession of vegetation in the Bokuya of this country on the basis of the unsufficient experiences since 1936. But the author had fortunately an opportunity to investigate the main regions in Japan such as important Bokuya in the Tohoku District, in the volcanic zones of Aso, Kirishima and others. On the basis of these results the author will discuss the plant succession - starting from *Miscanthus* stage through *Imperata* and *Zoysia* stage up to the waste stage, as Ōseko concluded – hoping that it will be

useful aid to future researches in this field.

(i) *Miscanthus* stage grassland

The grassland of this stage is one of the communities, which are seen soon after forests have disappeared by some causes, and the most important among the grasslands which can be used as Bokuya. Thus the chief end of Bokuya management is to maintain this stage as much as possible.

In Japan, however, Bokuya is used carelessly by easygoing management of the live-stock farming, so that the grassland belonging to this stage has remarkably decreased.

As above mentioned, only 34 grasslands out of 76 –44.7%– remain in this stage grassland ; 22.3% of them are pure *Miscanthus* type grasslands. (The most ideal *Miscanthus* type grassland can be seen on the western foot of the Kirishima Volcano and in the middle southern part of the Fukuoka Prefecture.).

We must not, however, make ourselves easy about these grassland types, and it is noteworthy that *Pteridium* and *Artemisia*, which are inedible for live-stock, and *Zoysia* which shows lower productivity, have remarkably appeared in this stage. The appearance of these unvaluable grasses (10.5%) indicates, how declined the

Table 4. Number of grasslands in which any *Miscanthus, Imperata, Zoysia, Pteridium, Lespedeza* and *Sasa* have grown.

Name of grasses	By Yoshida		From reference data	
	Number of grasslands	% to basic total grassland number of each stage	Number of grasslands	% to basic total grassland number of each stage
Miscanthus stage	(34)	%	(269)	%
Imperata cylindrica	4	11.8	4	1.5
Zoysia japonica	9	26.5	24	8.9
Pteridium aquilinum	9	26.5	133	49.4
Lespedeza spp.	10	29.4	0	0
Sasa spp.	13	38.2	3	1.1
Zoysia stage	(24)		(72)	
Miscanthus sinensis	6	25.0	54	75.0
Pteridium aquilinum	11	45.8	55	76.4
Lespedeza spp.	1	4.2	54	75.0
Sasa stage	(14)		(4)	
Miscanthus sinensis	4	28.6	3	75.0
Lespedeza spp.	4	28.6	2	50.0
Imperate cylindrica	1	7.1	1	25.0
Pteridium aquilinum	1	7.1	1	25.0
Pteridium stage	(4)			
Miscanthus sinensis	1	25.0		
Zoysia japonica	2	50.0		
Lespedeza spp.	1	25.0		

Note : Parenthesized figures in the column "number of grasslands" indicate the basic total grassland number of each stage

grasslands of this stage are. And it must be especially noted that 31.6% (20.9%) of the *Zoysia* stage grasslands and 5.3% of the *Pteridium* stage grasslands, etc. have already appeared and seemed turned from *Miscanthus* stage grasslands.

As Tables 1 and 2 show, there has been no grassland type which contained *Imperata cylindrica* Beauv. var. *Koenigii* Durand et Shinz., viz. *Miscanthus-Imperata* type. According to the opinion of Ōseko, *Miscanthus-Imperata* type must appear before *Imperata-Miscanthus* type in the transitional stage in which *Miscanthus* as dominant species declines gradually and at last *Imperata* becomes dominant. However, it does not necessarily follow that in each grassland on *Miscanthus* stage *Imperata* would not appear ; in 4 grasslands—11.8%—from 34 *Miscanthus* stage we could observe some *Imperata* (Table 4). The frequency and cover degree of *Imperata* in this case are very small and out of question. According to the reference data 4 grasslands out of 269—1.5%—show the appearance of *Imperata* and in only one of these 4 (on the basis of researching of 1 m²) *Imperata* shows good growth. From the above mentioned it can be concluded that the appearance of *Imperata* in such a degree is not enough to indicate a transfer from the *Miscanthus* stage to the *Imperata* stage, and thus *Imperata* can be regarded merely as an accompanied species of *Miscanthus* stage.

(ii) *Imperata* stage grassland

Tables 1 and 2 show that there can be no grassland at this stage. Or in Bokuya biotic disturbances are so acute, that this stage would pass in a short time. But if this stage grassland could exist, it would be expected theoretically the appearance of various kinds of grassland types containing *Imperata* such as, a) *Miscanthus-Imperata* type, which must be before this stage as noted above, b) *Imperata-Miscanthus* type, which will appear just before the climax stage of *Imperata*, c) *Imperata* type in the climax stage of *Imperata*, d) *Imperata-Zoysia* type in the retrogressive season of *Imperata* stage and e) *Zoysia-Imperate* type, which appears before the climax stage of *Zoysia*.

Although the plant succession of vegetation is multifarious and can not always be theoretically carried out, any of these 5 theoretical grassland types will make development. However, there can be in practice no grassland type which proves the appearance of *Imperata* stage grassland, and it seems rather that *Imperata* is merely one of the accompanied species of the *Miscanthus* stage.

The author has investigated repeatedly this matter also in adjacent lands of Bokuya and found no sign which would show the appearance of this stage grassland. On the basis of these results it can be concluded that in Bokuya of Japan there is no grassland at this stage. There are river beds or embankments, in which *Imperata* is dominant ; we can, however, omit these cases, as they are outside of Bokuya.

For reference I wish to describe briefly the status of *Imperata* grassland, which I found in the Macassar Peninsula on Celebes Island. *Imperata* grasslands (Alang-along land) were observed there at 2 places, each great in area, one developed on a

flat land and the other on a hill land. They are pure communities which contain scarcely any other grass. As explained by natives *Imperata* is eaten by all kinds of domestic animals and wild deer. These like to eat only young leaves, but scarcely grown hard leaves. The grassland is, therefore, burned after a dry season, and young leaves again sprout out and are given to live-stock. But it seems that in recent years the growth of *Imperata* becomes more luxuriant and the area occupied by these grasslands increase remarkably. The development of these communities has been caused chiefly by the yearly burning, which expels other grasses.

The author therefore received the impression that communitites which have once been occupied by *Imperata* will never resign their position to other grasses and he could not find any grassland type which led to other lower vegetational grassland from this grassland. On the Celebes Island, therefore, *Imperata* stage can be mentioned by Oseko, and this stage came from a higher vegetative grassland.

The appearance of the *Imperata* climax stage grassland would also be seen in Japan on the following conditions :

a) Suitability of land for the growth of *Imperata*,
b) inedibility for live-stock,
c) yearly burning,
d) decrease of other grasses.

Burning is carried out everywhere in Japan, the degree of damage by grazing and mowing is as good as in the case of *Miscanthus*. However, it is a question, whether high grasslands in this country would suit to the growth of *Imperata*.

Thus the existance of the *Imperata* stage grassland mentioned by Ōseko can not be confirmed in Japan. Then what kind of grassland will appear, after the *Miscanthus* stage grassland ceases to exist ? It is a matter, which must be studied furthermore in the future. Among the 3 stage grasslands, viz., *Zoysia* stage, *Sasa* stage and *Pteridium* stage, we can indicate that the *Zoysia* stage grassland shows. The biggest appearance degree of 31. 6% (20.8%), the *Sasa* stage is 18.4% (1.2%) and the last is the *Pteridium* stage with 5.3% (0 %). From the percentage we can assume that the *Zoysia* stage grassland has the greatest possibility to appear after *Miscanthus* stage. It is, of course, a conclusion on the assumption that the *Miscanthus* stage grassland would appear prior to all other grasslands. Considerations on grasslands of the *Sasa* stage, *Pteridium* stage and *Zoysia* stage are given as follows.

(iii) *Sasa* stage grassland

Sasa spp. is naturally one of the plants which make the vegetative reproduction. It grows only in those places, where *Sasa* spp. already exists, and differs therefore from *Miscanthus* and others, which reproduce by seeds, viz. invade into distant places and grow there. In Bokuya the following phenomenon has often been observed. After the felling of trees the already existing *Sasa* spp. shows remarkable growth. At the some time by the gradual invasion of perennial and tall grass types such as

Miscanthus and others the *Miscanthus-Sasa* or *Sasa-Miscanthus* type grasslands appear occasionally, but when the injury by grazing is slight or none, *Miscanthus* and the other grasses will be overcome, and after *Sasa* stage grassland the brushwood stage will appear.

Usually, whoever, the injury by grazing is unavoidable and the *Sasa* stage grassland cannot resist against obstacles from the outside, so that this will gradually give place to the other gasses.[3)6)] But there are also such instances, that *Miscanthus* stage grassland appeared when not too much injury by grazing was done or that *Sasa* stage grassland was immediately changed into *Zoysia* stage by overgrazing.[4)] On the other hand we can see such instances when the grassland of this stage can be used continuously under good management as grazing land as well as mowing land. In any case *Sasa* grassland as Bokuya is poor in continuation, as *Sasa* spp. itself is weak, and not quite able to appear independently, removing the other grasses under the biotic disturbances.

This stage grassland exists approximately in the same period as in the *Miscanthus* stage and appears after forest- and brushwood stage. It can be fairly continued, if suitably managed, but declines remarkably, if used heavily. There is, therefore, scarcely possibility that *Sasa* stage grassland would appear instead of the *Miscanthus* stage grassland under the conditions of overgrazing and burning.

(iv) *Pteridium* stage grassland

While there are many grasslands of this stage in foreign countries, grasslands in the climax stage of *Pteridium* are very few in Japan and indicate only 5.3%. *Miscanthus-Pteridium* type grassland, which contains a good deal of *Pteridium* shows, according to my investigation, only 3.9%, by the reference data, however, the percentage reached to 37.7%. In *Zoysia* stage grassland *Zoysia-Pteridium* type is 8.0%.

The grasslands, which contain *Pteridium* more or less (Table 4), were found in 9 grasslands—26.5%—(133 grasslands—49.4%) in the *Miscanthus* stage and in 11 grasslands—45.8%—(55 grasslands—76.4%) in the *Zoysia* stage.

Thus there are many grasslands, which contain *Pteridium*, and because of its inedibility for live-stock and its reproduction by rhizomes, *Pteridium* is widely distributed in Bokuya. Under worse management of Bokuya, *Pteridium* will grow thicker, so that the *Preridium* stage grassland will be finally expected.

Pteridium is usually regarded as the grass, which intruded soon after the collapse of forest- and brushwood stage.[4)] However, *Pteridium*, which is seen at present in *Miscanthus* stage grasslands, will be that, which intruded approximately at the same time as *Miscanthus* or in the middle as well as later period of the *Miscanthus* stage, *i.e.* after the climax stage of the *Miscanthus*. On the other hand, *Pteridium* which, is seen in *Zoysia* stage, is regarded as that, which intruded in this stage or remains from the *Miscanthus* stage.

Pteridium is of a strong nature and ineradicable compared with *Sasa* spp.,

but its reproduction is slow. So it is difficult that *Pteridium* would overcome *Miscanthus* in a short term, while *Zoysia* which is weak in the shade and not tall, can be overcome easily. All the *Pteridium* stage grasslands, which we observed, were in these cases. It is also noteworthy that the *Zoysia* stage grasslands, which contain *Pteridium*, are 45.8%; however, the *Miscanthus* stage grasslands containing *Pteridium* indicate only 26.5%. And moreover there is the *Miscanthus-Pteridium* type, but no *Pteridium-Miscanthus* type, and in the *Pteridium* stage grassland we can find the *Pteridium-Zoysia* type.

On the basis of these results it can be theoretically deduced that *Pteridium* can overcome other grasses easier in the *Zoysia* stage than in any other stage, setting aside the time of invasion. Naturally there is perhaps a possibility to overcome the *Miscanthus* in some cases of management, but it is easier to confirm the appearance of the *Pteridium* stage after the *Zoysia* stage than that just after the *Miscanthus* stage grassland.

(v) *Zoysia* stage grassland

As above stated, there is entirely no *Imperata* stage grassland and it is statistically most possible that this *Zoysia* stage grassland appears after the *Miscanthus* stage. It was further noted that the *Sasa* stage grassland is not appear after the *Miscanthus* stage according to its appearance process, and that the *Pteridium* stage grassland can appear after the *Miscanthus* stage. In some cases, however, its appearance after the *Zoysia* stage is usually easier to find.

It can, therefore, be concluded that next to the *Miscanthus* stage grassland the *Zoysia* stage will appear. In these cases we can expect theoretically the appearance of 3 types, viz., the *Miscanthus-Zoysia*, the *Zoysia-Miscanthus* and the *Zoysia* types. These 3 types are actually exist the *Miscanthus-Zoysia* type—5.3%—(0.3%), the *Zoysia-Miscanthus* type—5.3%—(15.6%) and the *Zoysia* type 14.5% (4.3%), respectively. The author attempted a theoretical confirmation on the basis of the grassland types, which is to appear, and on their percentage. In the case of heavy grazing it can be observed that the forest (or brushwood) stage turns to *Zoysia* stage directly without passing through the *Miscanthus* stage.[4] Such a plant succession will be confirmed also by the instances which we found in vast Bokuya on the Somma of Aso and in Iwate Prefecture. Around those settlements, the grassland types vary according to the distance. (There are *Zoysia* stage grassland, near the villages, while far from them are mixed *Miscanthus* and other tall grasses, and there are also the *Miscanthus* stage grsslands.) It is a typical change caused by the extensive management of Bokuya, that an area near the village has been laid waste by incessant grazing and that far from it, it maintains tall types because of less utilizing.

This relationwhip can be clearly demonstrated by the instances observed on the Celebes Island, where the extremely extensive management is usually performed and around the settlements short grass type grassland, mixed type grassland and

tall grass type grassland extend like a concentric circle. These cases show well the plant succession of Bokuya caused by biotic disturbances.

Judging from the facts mentioned above it is to be believed that the plant succession of Bokuya in Japan does not occur in the order of *Miscanthus* stage-*Imperata* stage-*Zoysia* stage-waste stage, but *Miscanthus* stage, *Zoysia* stage-waste stage.

Although it would be desirable to refer to many other instances, we believe that the results described in the present paper and the reference data are enough to draw the conclusion as above mentioned.

It has been hitherto believed that after the *Miscanthus* stage the *Imperata* stage would appear and, therefore, it would need too much time to have changed into the *Zoysia* stage productivity which is very low in Bokuya. Ōseko stated that it would need at least 5 to 15 years for the change from the *Miscanthus* stage to the *Imperata* stage, as well as from the *Imperata* stage to the *Zoysia* stage. As there can be no *Imperata* stage, the vegetation of Bokuya will decline in a short period. As above mentioned there are instances when through heavy grazing the *Zoysia* stage appeared without passing through the *Miscanthus* stage. We must therefore give careful consideration especially to the management of Bokuya.

In some cases those grasslands, which are regarded as the waste stage grasslands are classified in the *Zoysia* stage for convenience sake. These are especially seen in the Aomori Prefecture where in some cases *Zoysia* vegetates thinly, other small grasses inedible for live-stick grow in groupingly or openly, and bare ground is exposed, so that they have scarcely any utilizing value as Bokuya and are merely playgrounds.

The author has described the plant succession according to its classification by the main grasses. He based this classification in only 76 grasslands, in 50 Bokuyas, which are not enough to decide the character of all the Bokuya in Japan covering an area of circa 1,500,000 hectares. However, we believe that the conclusion in the present paper is in general correct and will add to this research field.

Summary

1. The author studied the plant succession of vegetation in Bokuya in 50 places in Japan (76 grasslands). On the basis of the results obtained grasslands of Bokuya were classified according to the main constitutional grasses into 4 grassland stages and to 15 grassland types.

The grasses, which decide these stages, are 4, viz., *Miscanthus sinensis*. *Zoysia* sp., *Sasa* spp. and *Pteridium aquilinum*, and those which decide the grassland types are 8, viz., *Artemisia* spp., *Trifolium repens*, *Lespedeza* spp., *Rhododendron* spp. besides the above mentioned 4 grasses. These grasses (contain 2 shrubby plants), which are small in number and limited, compose all the grassland types of Bokuya in Japan.

2. The grassland types, which belong to the *Miscanthus* stage grasslands

are 6, those belonging to the *Zoysia* stage are 5, those belonging to the *Sasa* stage are 2, and those which belong to the *Pteridium* stage are also 2.

3. The percentage of appearance in the *Miscanthus* stage grassland is 44.7%—the highest—, that in the *Zoysia* stage 31.6%, that in the *Sasa* stage 18.4% and in *Pteridium* stage is 5.3%.

These results indicate that Bokuya in Japan is more than half occupied by the *Miscanthus* stage and *Sasa* stage grasslands, which are still enough of valuable use. On the other hand *Pteridium* and *Artemisia*, which are inedible for live-stock, and *Zoysia* of low productivity have remarkably appeared, so that the grazing capacity of Bokuya shows a marked fall.

4. Concerning the kinds of grasses in each stage grassland there are in the *Miscanthus* stage various valuable grasses, while in the *Zoysia* stage the valuable grasses have been remarkably decreased and simplified. This declining tendency is more notable in the *Pteridium* stage grassland.

5. According to the study on the plant succession by Ōseko it is stated that 4 stage grasslands, viz., *Miscanthus*, *Imperata*, *Zoysia* and waste-stage will appear. By the results obtained by the author, however, the appearance of the *Imperata* stage grassland can be confirmed in no case. The appearance of the *Imperata* stage will be expected under the following conditions : 1) burning, 2) inedibility for live-stock, 3) suitability of land for the growth of *Imperata*, 4) decrease of other grasses. It seems mountainous lands in Japan are not suitable for the development of *Imperata*.

6. Thus no *Imperata* stage grassland can exist. Then what stage will appear after the *Miscanthus* stage grassland? As the *Sasa* stage grassland is weak and can not resist against obstacles from the outside, it is impossible to overcome the *Miscanthus*. The *Pteridium* is of a strong nature and resists against burning and furthermore is inedible for live-stock. It may possibly appear after the *Miscanthus* stage, but at present it does not actually occur in most cases. Then we may conclude that after the *Miscanthus* stage the *Zoysia* stage will appear. The appearance of this stage shows the greatest percentage next to the *Miscanthus* stage, and each grassland type, which is expected theoretically in this stage, can actually be observed.

This process of the plant succession—the appearance of the *Zoysia* stage after the *Miscanthus* stage—can be demonstrated by the instances that in Bokuya, which is wide and managed extensively, various grasslands in the order of *Zoysia* grassland—*Zoysia Miscanthus* mixed grassland—*Miscanthus* grassland are observed around settlements.

7. As the scale of the present study is not enough to decide the character of all the Bokuyas in this country, we entertain expectations of further researches.

Literature

(1) M. Oseko, Study on the grassland in Japan (in Japanese), 1937.
(2) Y. Yoshii, Y. Yoshioka and I. Iwata, Ecolog. Rev., **6** (1940).

(3) Ditto., Ecolog. Rev., **6** (1940).
(4) Ditto., Ecolög. Rev., **6** (1941).
(5) W. Sampson, Range and pasture management, 1923.
(6) S. Yoshida, Bull. Inst. Agr. Res. Tohoku Univ. (in Japanese), **2** (1950).

Plate I.

Fig. 2. *Miscanthus* stage grassland (*Miscanthus* type)

Fig. 3. *Sasa* stage grassland (*Sasa* type)

Plate II.

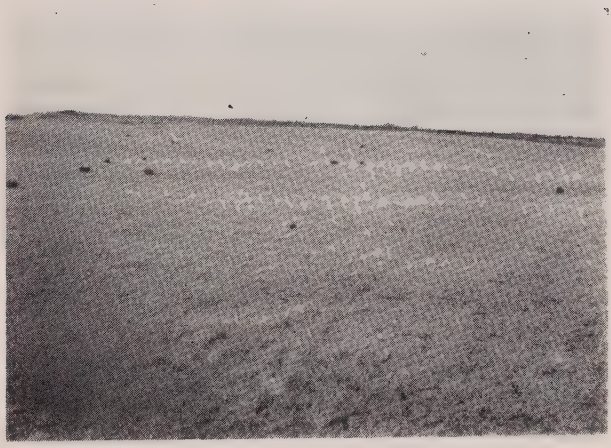


Fig. 4. *Zoysia* stage grassland (*Zoysia* type)

Fig. 5. *Pteridium* stage grassland (*Pteridium—Zoysia* type)

Plate III.

Fig. 6. Waste stage grassland (There have seen *Zoysia japonica* Steud., *Trofolium repens* L., and *Plantago major* L. var. *asiatica* Decne., and especially bare-ground)

A Study of Tuberization in the Potato Plant*

Morphological and Anatomical Observations on the General Process of Tuberization

Kengo YAMAMOTO and Kenji NODA

(Received October 1, 1949)

I. Introduction

Although a fundamental investigation concerning the tuberization process in the potato plant has an important significance for the improvement of potato cropping technique, it has hitherto been carried out unsatisfactorily. Projects of research on this problem are to be made along such lines as on the morphological observations of tuberization process, the environmental influences upon tuber formation and enlargement, and the differences among various potato varieties. So the writers have promoted investigation along these lines since 1945.

It is the aim of this paper to present the results of morphological and anatomical observations on tuberization process, which were based upon the results obtained by field observations and laboratory works, which had been conducted during the years of 1946, 1947 and 1948.

Anatomical observations on growing tuber of potato plant were formerly reported by Reed (1910) and Artshwager (1916). The change in chemical composition of a tuber during its development was traced by Girard (1891), and Sigh and Mather (1938). The latter also noticed the change in respiration of a tuber. In our country the observations on tuberization were made by Kouda (1935), Kawakami (1937), Nakamura (1938), and Uchida and Taguchi (1943).

Bald, Norris and Dickson (1941) observed the morphological changes of growing tuber and distinguished three stages during its enlargement. Gleisenegger (1933) measured the width, length and thickness of tuber successively during the development. Calorus (1937), and Inami and Sato (1939) reported the changes of fertilizer absorption in proportion to the growth stage.

II. Materials and general methods

The potato variety employed in our experiments was Irish Cobbler (Danshaku

* The 17th report of the Institute for Agricultural Research, Tohoku University. (1951)

in Japanese name), which was produced at Hokkaido District. The seed tubers were cut in about the same weight (ca. 30 g) and bedded in a cold frame for sprouting. They were sown in the experimental field in our Institute on April 15 in 1946, and 20 in 1947 and 1948, respectively. Before sowing young sprouts emerged from each tuber were cut off leaving a proper one.

As the experimental soil, sieved sandy loam soil was employed. Forty grams of ammonium sulphate and calcium superphosphate, twenty grams of potassium chloride, and some barnyard manures were given per a ridge (2 meters long), on which eight plants were grown.

The first investigation was made on the 5th day after sprouting in 1946 and 1947, and on the sprouting stage in 1948. The writers considered the sprouting stage as the time when a sprout just appeared above ground. Thereafter the investigations in each stage were made successively in every five day. Number of the used plants and average date of investigation in respective year are shown in the following table.

Anatomical observations were made microscopically on the preparations made by means of hand and microtom section. As the fixatives various reagents were tested and among them the best results were obtained by Bouin's fluid. The thickness of a section was 30 μ. In the procedure for making up preparations it required a careful treatment to dehydrate the fixed materials, especially rich in starch grains, not to be so hardened for cutting by microtom.

III. Results of observation

1. Plant growth and tuberization

(i) Plant height

The increase of plant height was slow at first and became rapid gradually with the progress of plant growth. The inflection point of the growth curve

Table 1. Number of plants used

Item	Number of days after sprouting / Simbol of growth stage / Year	0	5	10	15	20	25
		S	A	B	C	D	E
Number of plants used	1946	—	10	8	10	9	10
	1947	—	9	9	8	10	9
	1948	4	5	5	5	5	5
Average date investigated	1946	—	April 17.6	22.7	28.1	May 2.0	7.0
	1947	April 12.5	17.5	22.0	27.0	May 2.6	6.7
	1948	April 5.6	10.6	15.8	20.8	25.8	30.6

corresponded to about the fifteenth or twentyth day after sprouting (stage C or D), and thereafter the growth became slow again and almost stopped finally. The period of the maximum growth corresponded to the final stage above mentioned, which was at about the fourty-fifth day after sprouting (stage I) in 1947 and1 948. After this period the plant height did not further increase, strictly saying, it showed rather a slight decrease with the withering at plant top. However, in 1946 the increase of plant height continued until the final stage. The writers considered this phenomenon as an abnormal secondary development induced by a long lasted rain. The trend of changes in plant height in each year is shown in Table 2. It was represented by a S-shaped curve.

Table 2. Chages in plant height during development stages in each of three years (unit : cm).

Stage \ Year	1946	1947	1948
S	—	—	2.7
A	10.1	10.2	7.5
B	14.1	17.2	14.0
C	20.0	25.0	24.0
D	29.0	33.5	35.0
E	39.3	45.4	47.3
F	44.7	48.4	53.4
G	51.8	50.0	59.0
H	59.2	49.1	64.4
I	60.4	49.7	68.8
J	66.0	53.0	65.0
K	69.1	48.3	64.0
L	75.2	48.0	66.3
M	80.0	44.7	61.8
N	81.1	—	—

(ii) Weight of plant-top and -leaf

The growth of plant-top and -leaf was traced by weighing them successively in each stage. The results are shown in Table 3. Their growth curves showed S-shaped ones alike to that of the plant height, but the periods of their maximum development delayed slightly in comparison with that of the latter ; namely, the fiftyth day after sprouting (stage J) in 1946 and 1948, and the fourty-fifth day after sprouting

and average date of investigation.

30	35	40	45	50	55	60	65	70
F	G	H	I	J	K	L	M	N
10	10	9	9	9	10	9	9	10
8	10	9	8	10	10	9	9	9
5	5	5	5	5	5	5	5	—
12.4	17.6	22.1	27.8	June 2.7	7.8	12.5	17.9	22.8
13.4	18.1	22.2	27.1	June 1.5	6.5	13.3	18.7	24.5
May 6.0	10.2	15.6	21.2	25.7	June 0.4	4.8	9.9	—

(stage I) in 1947, respectively. Their inflection points on the growth curves also situated more or less behind that of plant height. After the period of maximum development, tops and leaves began to wither. Withering process was slow at first and gradually became rapid. Their trends are represented by the formula $Y=b-aX^2$. On the mathematical treatment of the growth curves of potato plant the writers will described in future reports.

In order to examine the relationship between the top and leaf growth the ratios between them in each stage were calculated. They are shown in Table. 4.

According to Table 4 the top-leaf ratio was more or less constant (about 2) until the time of maximum development, and then increased rapidly. Such tendency was observed in every year. Consequently it was considered that the growth rates of top and leaf were similar until their maximum growths, and then the ratio became favorable to the former by its less remarkable withering than that of the latter. The growth of

Table 3. Changes in weights of plant top and leaf during development stages in each of three years (unit : gram).

Year / Plant / Stage	1946		1947		1948	
	Top	Leaf	Top	Leaf	Top	Leaf
S	—	—L	—	—	0.9	0.4
A	7.5	4.1	11.7	6.7	6.5	4.4
B	23.4	15.4	28.8	16.1	22.2	13.5
C	38.7	30.7	74.8	41.9	65.2	37.4
D	94.4	56.7	97.5	53.0	134.7	65.9
E	135.6	75.7	148.0	72.7	243.0	111.0
F	168.4	89.8	168.9	79.7	337.3	144.4
G	216.7	115.7	189.0	95.0	402.0	170.0
H	205.0	104.3	180.0	87.4	487.4	196.4
I	233.9	103.8	148.0	79.5	480.0	212.0
J	281.7	139.5	142.7	72.4	489.6	219.6
K	245.9	119.5	120.6	54.9	423.0	193.0
L	258.9	95.9	95.6	33.2	396.0	116.0
M	231.1	66.7	58.1	5.0	121.0	—
N	181.7	58.8	—	—	—	—

Table 4. Changes in ratio of leaf weight to top weight during development stages in each of three years.

Year / Stage	1946	1947	1948
S	—	—	(2.50)
A	1.83	1.75	1.48
B	1.52	1.79	1.65
C	1.26	1.79	1.74
D	1.66	1.84	2.04
E	1.79	2.04	2.19
F	1.89	2.12	2.34
G	1.87	2.00	2.36
H	1.96	2.06	2.48
I	2.25	1.86	2.27
J	2.02	1.97	2.23
K	2.05	2.20	2.19
L	2.70	2.88	3.41
M	3.46	11.62	—
N	3.09	—	—

aerial parts of a plant is shown in plates I, II and III.

The stolon of potato plant emerged from the node of subterranean part of a main stem as soon as it sprouted (about the second day after sprouting). At the time of emergence the plant height was about 3 cm, the number of leaves 6 – 9, the leaf weight 0.5 – 1.0 g, and the top weight 0.3 – 1.0 g. The stolon length was 0.15 – 0.4 cm in average. The results are shown in Table 5.

Table 5. States of growth of terrestrial and subterranean parts, and shapes of growing point on top of terrestrial main stem until the third day after sprouting.

Plant	Number of days after sp.	Plant height cm	Number of leaves	Leaf weight g	Top weight g	Number of stolons per one plant	Stolon length cm	Growing point of top
1	0	3.1	8	0.40	0.60	4	0.15	*
2	0	2.4	6	0.40	0.30	4	0.33	*
3	0	2.5	9	0.45	0.60	4	0.25	**
4	0	2.6	7	0.30	0.50	6	0.27	**
5	1	3.0	9	0.90	0.60	3	0.37	*
6	1	3.3	8	1.10	0.80	4	0.18	**
7	2	3.1	9	1.00	0.70	3	0.10	*
8	2	4.2	10	1.70	1.30	4	0.40	**
9	3	4.3	9	1.30	1.00	6	0.37	**
10	3	4.8	8	1.40	1.30	3	0.23	**

* Flatt vegetative cone.
** Sepal emergence.

From Table 5 it can be seen that the time of stolon emergence corresponds to that of the differentiation of flower organ in the growing point of the plant top. There could be observed a remarkable variation in length among different stolons, and it was not resulted from the different position of emergence on the subterranean main stem. The period from stolon emergence to cessation of elongation is the stolon elongation period, which goes on for about ten or fifteen days (Plate IV – Photos. 10 and 11).

(iv) Formation of tuber

The tip of stolon began to swell into a spindle shape as soon as elongation ceased and then gradually changed its form. This duration was divided into the following four stages (named "tuberizing stage") from the morphological standpoint : At first the tip of stolon elongates at the growing point (I : stolon elongation period, Photo. 22a) ; after cessation of elongation a slight swelling occurs and then turns into a spindel shape (II : Photo. 22b); it becomes spherical and scaly leaf at the terminal part still remains (III : Photo. 22c) ; and finally scaly leaf disappears and morphological completion of a tuber attains, and the eyes are clearly seen arranging spirally (IV : Photo. 22d). The weight of a tuber at this stage is lighter than 1 g. And the stolon tip, heavier than 1 g, was regarded as an enlarging tuber and represented by symbol T in Table 6. The percentages of the stolons belonging to each stage to the total stolons are shown in Table 6.

Table 6. The percentages of the number of stolons belonging to each of five tuberizing stages to the total number at each growth stage.

Year / Growth stage *	1946					1947				
	I	II	III	IV	T	I	II	III	IV	T
A	100.0					100.0				
B	100.0					100.0				
C	19.4	23.8	55.2	1.5		18.1	39.0	37.5	5.6	
D		4.6	44.1	25.5	25.5	0.9	12.6	33.4	15.3	37.8
E		1.1	34.0	11.3	53.4		6.8	27.2	17.5	48.5
F		2.7	36.0	12.1	48.6		8.8	30.4	15.7	45.1
G		4.0	10.2	13.5	62.1		8.8	25.7	17.7	47.8
H			21.2	15.1	63.4		12.7	20.0	18.2	49.1
I			11.7	19.1	69.1		8.1	24.4	27.9	39.1
J			20.6	21.2	68.1		8.9	19.8	20.8	49.5
K			12.1	4.5	83.3		4.0	24.8	22.8	48.5
L			12.0	10.2	77.5		1.3	18.7	18.7	61.5
M			8.4	13.5	77.9			6.9	17.2	75.9
N			6.4	16.1	77.4		—	—	—	—

* Tuberizing stage ; cf. text.

Table 7. Changes of the length of stolon and the number of stolons in proportion to the plant growth.

Year	Growth stage	Average length of stolon (cm)	Number of stolons per one plant	Available stolon		Non-available stolon	
				Length (cm)	Number	Length (cm)	Number
1946	A	1.20	4.00				
	B	2.45	5.88				
	C	3.13	6.70				
	D	2.67	9.56	4.67	2.44	1.98	7.11
	E	3.48	8.80	5.09	4.70	1.64	4.10
	F	3.59	7.40	5.95	3.60	1.52	3.80
	G	3.59	7.40	4.57	4.60	1.03	2.80
	H	3.64	7.33	4.55	4.67	2.05	2.67
	I	3.80	7.56	4.62	5.22	1.97	2.33
	J	3.67	7.33	4.61	5.00	1.66	2.33
	K	4.59	6.60	5.15	5.50	1.79	1.10
	L	4.37	6.44	5.18	5.00	1.56	1.56
	M	5.05	6.56	5.91	5.11	2.02	1.56
	N	4.13	6.20	4.89	4.80	1.53	1.40
1947	A	0.66	4.67				
	B	2.71	6.00				
	C	4.27	9.00				
	D	3.80	11.10	6.17	4.20	2.36	6.90
	E	4.15	11.44	5.56	6.17	2.25	5.89
	F	3.96	12.75	6.35	5.75	1.99	7.00
	G	4.11	11.30	6.18	5.40	2.23	5.90
	H	4.45	11.00	7.35	6.00	1.65	6.22
	I	3.38	10.75	5.74	4.25	1.83	6.50
	J	4.41	10.10	6.67	5.00	2.19	5.10
	K	4.44	10.10	7.03	4.90	1.99	5.20
	L	4.54	7.50	6.07	5.11	2.12	3.22
	M	5.54	6.44	6.51	4.89	2.50	1.56

All the stolons at the growth stages A and B belonged to the stage I, and those at the growth stages C and D showed the maximum percentages at the stage II, III or IV, and those at E showed that at T.

Thus the writer regarded the above duration from stage C to E as the "tuber formation period" in the course of the process of plant growth and this duration lasted for about 10 or 15 days (Plate IV—Photos. 12, 13 and 14). At this period the secondary stolon also began to emerge as seen in Table 7, and they were short in length and almost non-available (non-tuberizing) even in the later stages of tuber enlargement. However, the writers considered that such stolons might be perhaps able to turn into available ones by the favorable changes of environmental conditions. The decrease of the number of non-available stolons in the later stages of growth as seen in Table 7 might be caused by their disappearance (perhaps by absorption).

(v) Enlargement and completion of tuber

Thus the morphologically performed tuber enlarged rapidly for about five weeks (the tuber enlargement period) ; it occurred from E to L stage in 1946 and 1947, and from E or F to L stage in 1948. Then the rate of enlargement decreased suddenly and stopped finally. It was the tuber completion period and its duration was about ten days before harvesting. It is considered that a morphological completion of a tuber is attained at this final stage.

Table 8. Development of tuber during the plant growth in each of three years.

Year	Stage	Tuber weight per one plant (g)	Average weight of one tuber (g)	Number of tubers per one plant
1946	D	6.7	2.8	2.4
	E	29.8	6.3	4.7
	F	72.2	20.1	3.6
	G	134.8	29.3	4.6
	H	165.7	36.0	4.6
	I	190.2	36.6	5.2
	J	312.7	63.8	4.9
	K	254.0	46.2	5.5
	L	305.0	61.0	5.0
	M	371.2	74.2	5.0
	N	327.3	68.2	4.8
1947	D	12.1	2.8	4.4
	E	56.7	9.3	6.1
	F	73.7	12.1	6.1
	G	119.5	21.7	5.5
	H	186.5	31.1	6.0
	I	167.5	33.5	5.0
	J	215.6	39.9	5.4
	K	264.7	53.8	4.9
	L	272.2	52.4	5.2
	M	325.9	63.9	5.1
	N	325.2	73.9	4.4
1948	E	8.3	3.2	2.6
	F	34.0	13.1	2.6
	G	134.1	29.1	4.6
	H	201.2	55.9	7.2
	I	330.6	57.0	5.8
	J	447.0	68.9	6.4
	K	700.8	104.1	6.8
	L	783.2	115.2	6.8
	M	814.4	104.4	7.8

The changes in number of tubers and tuber weight per one plant, and the average weight of a tuber are shown in Table 8. The time of the maximum tuber weight per a plant varied in each year, but the increasing rate of tuber weight in respective year was identical with each other. The

number of tubers per a plant was already decided at the beginning of the enlargement period, but strictly saying it showed a slight decrease in the last stage of growth (the tuber completion period). It may be induced by the disappearance (perhaps by absorption) of some smallest tubers.

All tubers could be classified into the following three groups by their different weights ; small tuber (lighter than 30 g), medium one (30 – 90 g) and large one (heavier than 90 g). The results obtained in 1946 and 1947 are shown in Table 9.

Table 9. Changes of number of tuber per one plant belonging to each of three groups classified by their weight.

Stage	1946			1947		
	Small tuber	Medium tuber	Large tuber	Small tuber	Medium tuber	Large tuber
D	4.4			4.4		
E	2.7			6.1		
F	3.3	0.3		5.8	0.4	
G	2.4	2.2		3.4	2.1	
H	2.2	2.2	0.2	2.8	3.2	
I	2.2	2.9	0.1	2.1	2.4	0.5
J	1.4	2.3	1.2	2.3	2.7	0.4
K	1.6	3.3	0.6	1.4	2.5	1.0
L	1.1	2.6	1.3	1.7	2.7	0.8
M	1.1	2.5	1.4	1.7	2.0	1.4
N	1.4	1.7	1.7	1.8	1.4	1.2

The number of small tubers reached to the maximum at the beginning of the enlargement period (stage E or F), then decreased rapidly by arising of large ones, and became constant in number since the 50th day after sprouting. Medium ones arose on the 30th day after sprouting (stage F) and increased in number by rapid development of small tubers. The maximum number was attained by the 45th or 50th day after sprouting and its percentage to the total number still increased

Table 10. Changes in ratio of tuber weight to plant top or leaf weight in each of three years.

Stage	1946		1947		1948	
	Tuber-top ratio	Tuber-leaf ratio	Tuber-top ratio	Tuber-leaf ratio	Tuber-top ratio	Tuber-leaf ratio
D	0.07	0.12	0.12	0.23	—	—
E	0.22	0.39	0.38	0.78	0.03	0.08
F	0.43	0.80	0.44	0.92	0.10	0.24
G	0.62	1.17	0.63	1.25	0.33	0.79
H	0.18	1.59	1.04	2.13	0.41	1.03
I	0.81	1.83	1.13	2.11	0.69	1.56
J	1.11	2.24	1.51	2.98	0.91	2.04
K	1.03	2.12	2.19	4.82	1.66	3.63
L	1.18	3.18	2.85	8.21	1.98	6.75
M	1.61	5.56	6.61	65.18	6.73	—
N	1.80	5.56	—	—	—	—

toward the final stage of development.

The relation between the tuber development and the growth of plant top or leaf was examined by calculating the ratio of tuber-top or tuber-leaf, based on the results given in Tables 3 and 8. The results are shown in Table 10.

This ratio gradually increased until the maximum growth stage of plant top and rapidly from the 50th day after sprouting. This fact showed that the plant top began to wither at the 50th day, but the tuber enlargement continued until the later stage.

2. Anatomical observations of tuberization

The results observed from a morphological standpoint upon the process of tuberization of potato plant were described in the previous section. In this section the results observed from an anatomical standpoint, which were made in 1947 and 1948, will be described.

(i) Emergence and elongation of stolon

The stem of potato plant was composed of epidermis, outer and inner cortexes, endodermis, vascular tissue, and outer and inner medullae. Vascular tissue is amphiphloic bicolateral, and the development of the inner bundle was very weak, being chiefly composed of a primary elements.

The structure of stolon was identical to that of a stem described above. The stolon emerged exogenously from the node of subterranean main stem and elongated rapidly by active cell division in its terminal region. The vascular bundle tissue developed only weakly similar to that of stem.

Number of cell-layers and cell size in each tissue of stolon were the most superior in medullae as shown in Table 11.

Table 11. Number of cell layers and size of cell in the cross section of a elongating stolon.

Tissue	Number of cell layers	Size of cell		
		Radial length (μ)	Tangential length (μ)	Longitudinal length (μ)
Epidermis	1	23.88	24.22	91.18
Outer cortex	2～ 4	21.71	25.05	100.20
Inner cortex	5～10	36.41	38.41	105.21
Medulla	7～15	55.11	—	142.62

(ii) Formation of tuber

The elongation of stolon stopped on the 10th or 15th day after sprouting and began to swell, namely, a stolon began to change into a tuber at this period, and this changing process could be divided into four stages as already described. The anatomical observations were made on the growing tuber in each four stages.

(a) Development of tissue in tuber. The degree of the development of a cork layer, outer and inner cortexes, and central cylinder (phloem parenchyma and

medulla), and the results are shown in Table 12.

Table 12. Changes in tissue area during four stages from stolon to tuber.

Stage	Epidermis	Cork layer	Outer cortex	Inner cortex	Central cylinder	Phloem parenchyma	Medulla
I	0.05	—	1.59	3.93	3.14	0.82	2.07
II	0.80	—	1.77	6.18	5.64	3.02	2.54
III	1.27	3.62	3.21	14.69	25.48	10.99	13.17
IV	2.66	9.21	6.99	33.56	94.48	35.08	50.77

The increase of the area from stage I to IV was the greatest in central cylinder, and especially greater in medulla than in phloem parenchyma. However, the increasing rate from stage I to IV was greater in phloem parenchyma (about 43 times) than in medulla (about 25 times). Such rapid increase of the area in the above both tissues was induced by active cell-division in cambium of vascular tissue, and was a characteristic feature in the period changing from stolon into tuber.

(b) Increase of cell size. As the increase of cell size and number of cells are two main factors for the development of a tuber, the writers observed firstly the changes of cell size in the four stages by measuring the radial, tangential and longitudinal lengths of cell in cortex and medulla, of which a tuber was mainly composed. In the cell of medulla the radial and tangential lengths could not be distinguished one another.

Tabe 13. Changes in cell size during four stages from stolon to tuber (unit : μ).

Stage	Cortex			Medulla	
	Radial length	Tangential length	Longitudinal length	Transverse length	Longitudinal length
I	38.7	38.4	52.9	38.2	45.9
II	42.6	52.3	55.3	48.8	58.0
III	47.9	51.8	58.5	57.6	59.8
IV	50.1	58.5	61.8	74.3	79.3

As seen from Table 13, in cortex the radial and tangential lengths of a cell increased only slightly and the longitudinal length did hardly ; on the other hand, in medulla both the transverse and longitudinal lengths increased greatly.

(c) Increase of cell number. The increase in number of cells of a tuber is the other main factor for the development of a tuber and is induced by cell division. The writers traced the increase in number of cells through four stages from stolon to tuber by counting the number of dividing cells per one microscopic field ($\times 500$). The results are shown in Table 14.

As shown in the Table 14, the number of dividing cells was the greatest in

Table 14. Number of dividing cells in each tissue of stage IV.

Tissue	Total number of field observed	Total number of dividing cells observed	Number of dividing cells per one field
Epidermal layer	271	94	0.35
Cortex	294	88	0.27
Cambium	248	127	0.51
Medulla	192	32	0.17

vascular tissue and phloem parenchyma, the next in epidermis or cortex, the less in medulla. From the above results it could be seen that the development of phloem parenchyma and medulla was the most vigorous by active cell division in vascular cambium, because cells formed successively from the cambium were organized externally into phloem parenchyma and internally into medulla.

Next the number of cell layers at each tissue in the cross section of a tuber was observed directly and its results are shown in Table 15.

Table 15. Changes in cell number during four stages from stolon to tuber.

Stage	Cork layer	Outer cortex	Inner cortex	Medulla
I	—	2∼3(2.4)	6∼ 8(6.3)	8∼10 (8.8)
II	—	2∼3(2.5)	6∼ 7(6.4)	10∼15(13.5)
III	2∼4(3.0)	2∼3(2.5)	6∼ 9(7.2)	20∼25(23.4)
IV	5∼6(5.5)	2∼3(2.3)	6∼10(7.3)	>25

As seen in Table 15, the tissues brought under the observation were epidermal layer, outer and inner cortexes, and medulla, and the increase was found to be the most conspicuous in medulla, the next in epidermal layer and the less in both cortexes.

(iii) Enlargement and completion of a tuber

The writers observed the changes of tissue- and cell-sizes in a tuber in proportion to its enlargement. The tubers used to this observation were selected comparatively larger ones among those produced at re-

Tabel 16. Average weight of tubers used to the anatomical observations at the respective stage of tuber enlargement and completion.

Stage	Number of days after sprouting	Average weight of tuber used (g)
E	25	5.0
F	30	19.3
G	35	52.5
H	40	75.0
I	45	103.5
J	50	145.8
K	55	185.5
L	60	210.0
M	65	231.0

spective nine growing stage as shown in Table 16. The number of tubers produced at one stage was from two to seven. Their average weights were also shown in Table 16.

(a) Development of tissue of a tuber. The investigation was made by measuring the area of each tissue in cross and longitudinal sections of a tuber, and the results are shown in Table 17.

Table 17. Increase in the area of each tissue during the process of tuber enlargement and completion.

Stage	Total (cm^2)	Cortex		Phloem parenchyma		Outer medulla		Inner medulla	
		size (cm^2)	%	size (cm^2)	%	size (cm^2)	%	size (cm^2)	%
E	3.34	0.62	18.6	0.98	29.3	1.62	48.5	0.12	3.6
F	7.22	1.40	19.4	1.80	24.9	3.66	50.7	0.36	5.0
G	17.56	2.48	14.1	4.28	24.4	9.74	55.5	1.06	6·0
H	18.00	2.42	13.4	4.88	27.1	9.78	54.3	0.92	5.2
I	21.79	2.49	11.4	5.61	25.9	12.86	59.0	0.83	3.9
J	26.91	3.33	12.4	7.33	27.2	15.17	56.4	1.08	4.0
K	30.59	3.73	12.2	8.90	29.0	16.98	55.3	1.08	3.5
L	34.26	4.35	12.7	9.13	26.6	19.18	56.0	1.60	4.7
M	40.15	6.04	15.0	10.06	25.1	22.17	55.2	1.88	4.7

The increase in the area of each tissue was parallel with that in tuber weight, and its trend could be, on the whole, expressed by a straight line, differing from the increasing rate of the latter. This tendency was seen similarly in both sections. In comparison with the increasing rate of each tissue, it was found to be the greatest in outer medulla, and less vigorous as in the following order, *viz.*, phloem parenchyma, cortex and inner medulla.

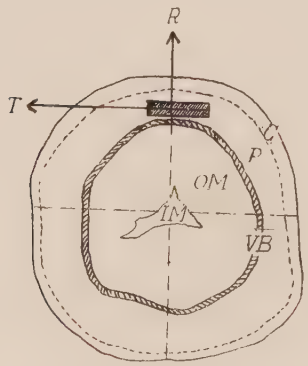


Fig. 1. Showing a transverse section of a potato tuber. C : cortex. V. B. : vascular bundle. P. : phloem parenchyma. O. M. : outer medulla. I. M. : inner medulla. R. : radial direction in the measurement of cell length. T. : tangential direction.

Next the percentage of the tissue area to the total area decreased in cortex and phloem parenchyma, while increased, though slightly, in outer and inner medullae until the tuber weight reached up to about 35 grams, and then it became constant. The percentages were about 13% in cortex, 25% in phloem parenchyma, 55% in outer medulla, and 4% in inner medulla.

(b) Increase of cell size. The measurement of cell size was made on about 100 cells of comparatively large size in each tissue by measuring its radial and tangential lengths (Fig. 1).

The increase in cell length was found to be most conspicuous until the tuber weight reached up to about 35 grams (30th day after sprouting), and then slowed down. It almost stopped when the tuber weight reached up to about 70 grams. The trend of the changes in increasing rate of cell length through successive measurements could be expressed with an exponential line, but its mathematical analysis would be performed by further investigation.

The tangential length of a cell was greater than the radial one in cortex, but in other tissues the essential difference between them could not be found.

Table 18. Increase of cell size at each tissue of a tuber during the process of tuber enlargement and completion (unit : μ)

Stage	Cortex		Phloem parenchyma		Outer medulla		Inner medulla	
	Tangential length	Radial length	Tangential length	Radial length	Tangential length	Radial length	Tangential length	Radial length
E	80.4	61.7	82.5	79.6	80.4	82.9	93.3	97.9
F	108.8	76.7	107.1	112.5	97.1	115.4	117.1	115.5
G	138.3	93.3	135.0	133.8	122.9	125.4	116.7	135.0
H	140.8	85.4	133.8	133.8	128.3	125.4	132.1	127.5
I	133.3	101.7	140.4	150.0	141.7	139.6	148.3	150.0
J	162.5	107.5	146.7	158.3	145.8	139.6	145.8	141.7
K	156.3	95.8	140.4	157.9	145.8	147.6	141.3	150.8
L	160.0	98.8	141.7	160.4	147.9	158.3	147.5	155.0
M	156.7	101.7	148.3	162.1	150.0	160.0	150.0	141.7

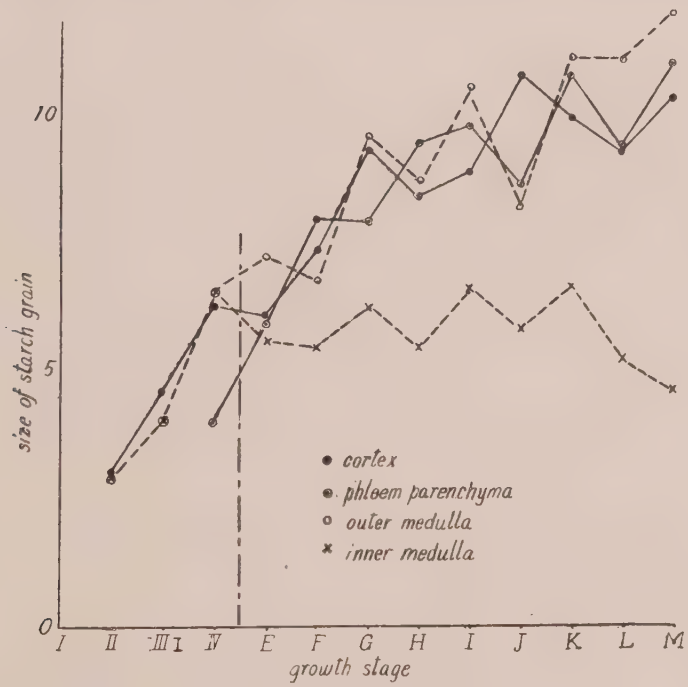


Fig. 2. Showing changes of average size (diameter) of starch grain in each tissue. (unit of size of starch grain : 1=about 0.6 μ)

(IV) Development of starch grain in tuber

Starch grains were firstly seen at the endodermis of a tuber as soon as stolon began to swell, and they were very small in size (about 5 μ in diameter). Then they came to be found in every tissue of a young tuber, increasing rapidly in number and size. Changes in average diameter of starch grain in each tissue are shown in Fig. 2.

In cortex, phloem parenchyma and outer medulla, the average diameter of starch grain increased rapidly in early stages, and then gradually slowed down in its increasing rate ; while in inner medulla it did not almost increase after the 25th day after sprouting.

It is an interesting problem to know the changes of the frequency distribution of variate in each class of the size (diameter) of a starch grain. The frequency curve and the degree of dispersion changed with the progress of stage, and the writers will carry out a mathematical analysis in future. The distribution in inner cortex is shown in Table 19.

Table 19. Frequency distribution of variate in each class of the size (diameter(1)) of starch grain in inner cortex.

Stage \ Class limits (2) (3)	(4)	—2	—4	—6	—8	—10	—12	—14	—16	—18	—20	—22	—24	—26	over 26
II	100	42	42	16											
	%	42.0(5)	42.0	16.0											
III	152	20	68	34	30										
	%	13.2	44.7	22.4	19.7										
IV	138	12	28	32	40	16	10								
	%	8.7	20.3	23.2	29.0	11.6	7.2								
E	198		38	88	62	4	6								
	%		19.2	44.4	31.3	2.0	3.0								
F	233	23	52	37	32	33	10	12	24	8	2				
	%	9.9	22.3	15.9	13.7	14.2	4.3	5.2	10.3	3.4	0.9				
G	167	2	28	22	42	14	6	12	28	4	5	3			
	%	1.2	16.8	13.2	25.1	8.4	3.6	7.2	16.8	2.4	3.0	1.8			
H	209	8	28	38	62	34	12	6	6	2	6	2	1	2	2
	%	3.8	13.4	18.2	29.7	16.3	5.7	2.9	2.9	1.0	2.9	1.0	0.5	1.0	1.0
I	208	4	26	48	42	28	16	14	8	12	8	2			
	%	1.9	12.5	23.2	20.2	13.9	7.7	7.0	3.8	5.8	3.8	1.0			
J	151	3	14	23	39	14	3	9	14	6	13	4	1	5	3
	%	2.0	9.3	15.2	25.8	9.3	2.0	6.0	9.3	4.0	8.6	2.6	0.7	3.3	2.0
K	144	2	14	20	45	22	7	3	13	4	4	2		4	4
	%	1.4	9.7	13.9	31.3	15.3	4.9	2.1	9.0	2.8	2.8	1.4		2.8	2.8
L	170	4	12	56	18	28	10	6	20	4	10				2
	%	2.4	7.1	32.9	10.6	16.5	5.9	3.5	11.8	2.4	5.9				1.2
M	128		8	28	26	18	20		14	2	2	2	2	4	2
	%		6.3	21.9	20.3	14.1	15.6		10.9	1.6	1.6	1.6	1.6	3.1	1.6

(1) Average length of long and short diameter.
(2) Classified by the scale of stage micrometer, 1=about 0.6 μ.
(3) For example, —2 shows class limits from 1 to 2.
(4) Total number of starch grain.
(5) Percentage.

IV. Discussion

The process of tuberization in potato plant could be distinguished in the following four periods, *viz.*, the stolon elongation, tuber formation, tuber enlargement and tuber completion periods. The time of transition from stolon elongation to tuber formation period had no connection with the different length of stolon and it occurred almost simultaneously in every stolon of the same plant. According to our observations from an anatomical standpoint, the active elongation of stolon at the terminal region changed into the lateral development of stolon-tip at the transition time described above and the most vigorous development was found in phloem parenchyma and medulla among various tissues of a tuber.

It can be supposed that the transition may be effected by a qualitative change which occurs in the life cycle of potato plant.

According to Artshwager (1916) the change from stolon to tuber occurred quite abruptly. Ogasa (1941) considered on the basis of his investigation on *Helianthus tuberosum* that the tuber development must be distinguished from the tuberization. Yasui (1946) also stated that the cessation of growth in the terminal region of stolon was induced by the formation of a secondary dividing tissue, enhanced by a newly translocated dividing hormone. It was considered previously that the above change might be caused by bacteria or a certain physical stimulus. Further studies concerning this problem should be conducted from a physiological standpoint.

Emergence of stolon on the subterranean main stem occurred almost simultaneously with the time of differentiation of flower organs in the growing point of plant top. This observation coincides with Yasui's suggestion (1946) that the emergence of stolon may be induced by the differentiation of flower organ.

All the tubers formed by the same plant began to tuberize almost at the same time, but came to differ from one another in weight in successive stages of their development. However, it was not yet decided whether the difference in tuber weight at the final stage may be attributable to the difference at the time of cessation of tuber development or it may be resulted by the difference in growing rate of a tuber. In order to clarify this problem the writers will accomplish further experiments by means of water culture of the plant, in which the enlargement process of an individual tuber will be traced directly throughout the development stage.

As previously stated, the writers concluded from their anatomical observations that the tuber enlargement was fulfilled by the increase in cell-size and -number until the later stage of development. While in the previous papers, for example, by Tukey and Young (1939) in sour cherry, Smith (1940) in apple, and Sinnot (1939) in cucumber, it was reported that the enlargement of fruit flesh was only fulfilled by the increase of cell-size after a certain period of enlargement. It is an interesting problem to know the cause of the difference between both types of enlargement.

In further the writers will study the quantitative relation between the increase of cell-size or cell-number and the tuber enlargement.

Greisenegger and Neudecker (1933) investigated the changes in the shape of a tuber during its development by measuring its length, width and thickness, and concluded that the decisive factor to the tuber enlargement was the increase in its length.

Bald, Norris and Dickson (1941) distinguished the following three successive stages in the course of tuber development, *viz.*, "the radial swelling of the stolon to form a tuber rudiment," "the swelling of the rudiment without change of shape", and "the elongation at a greater rate than radial expansion". It can be supposed that the first stage corresponds to the tuber formation period, and the second and third stages correspond to the tuber enlargement in our observation.

Summary

The writers made the morphological and anatomical observations concerning the tuberization in the potato plant during the years of 1946, 1947 and 1948. The results obtained are summarized as follows :

1. The writers could distinguish two periods in the growing process of the aerial part of potato, *viz.*, the development and withering periods.

2. The process of tuberization of the underground part could be divided into the following four periods, *viz.*, the stolon elongation, tuber formation, tuber enlargement and tuber completion periods.

3. Rapid enlargement of tuber (the tuber enlargement period) began at about the 25th day after sprouting and continued until the beginning of the tuber completion period. The growth curve was represented by a straight line.

4. In structure the stolon was identical to the stem. Its vascular tissue developed only weakly.

5. The stolon emerged at the time just after sprouting and elongated rapidly. Elongation was induced by active cell division in the terminal region of the stolon.

6. The development of tuber was mainly resulted from the increase of cell size and number, which was found to be the most vigorous in phloem parenchyma and medulla.

7. The increase in the area of each tissue was parallel with that in tuber weight and was the greatest especially in medulla and phloem parenchyma.

8. The development of phloem parenchyma and medulla was the most vigorous by active cell-division in vascular cambium, because cells formed successively from the cambium were organized externally into phloem parenchyma and internally into medulla.

9. Starch grains in a tuber were firstly seen at the endodermis of a young tuber and came to be found in every tissue, increasing in number and size in proportion to the development of tuber.

Literature cited

(1) E. F. Artschwager, Jour. Agr. Res., **14** (1916). 221.
(2) J. G. Bald, D. O. Norris and B. T. Dickson, Phytopath., **31** (1941), 181.
(3) B. N. Girard, Cited from K. Kawakami (1948), pp. 39., (1891).
(4) I. K. Greisenegger and Neudecker, Forts. Landw., **8** (1933), 169.
(5) G. Inami and K. Sato, Agr. and Hort. (in Japanese), **14** (1939), 1733.
(6) K. Kawakami, Agr. and Hort. (in Japanese),**13** (1938), 81.
(7) ———, Ibid. (in Japanese), **14** (1939), 413.
(8) ———, *Intorduction to potato cropping* (in Japanese), Tokyo (1948).
(9) S. Kowda, M. Ono and S. Igarashi, Agr. and Hort. (in Japanese), **10** (1935).
(10) S. Nakamura, Agr. and Hort. (in Japanese), **13** (1938), 1015.
(11) T. Ogasa, Report Inst. Sci. Res. Manchoukuo (in Japanese), **5** (1941), 451.
(12) T.Reed, Ann. Bot., **24** (1910), 1733.
(13) J. S. Shoemaker, *"Vegetable growing"* (chap. 10, potato), (1947).
(14) B. N. Sigh and P. B. Mathur, Ann. Appl. Biol., **24** (1937), 409.
(15) E. W. Sinnot, Amer. Jour. Bot., **25** (1938), 75.
(16) W. H. Smith, Jour. Pomol. and Hort. Sci., **18** (1940), 249.
(17) H. B. Tukey and J. O. Young, Bot. Gaz., **100** (1926), 723.
(18) S. Uchida and K. Taguchi, *"Potato"* (in Japanese), Sapporo (1943).
(19) K. Yamamoto and K. Noda, Seibutu (in Japanese), (1947), 37.
(20) K. Yasui, Collecting and Breeding (in Japanese), **8** (1946), 26.

Plate I.

Plate I. Showing the appearance of above-ground part of a potato plant at each stage after sprouting. 1 : the 5th day ; 2 : the 10th day ; 3 : the 15th day ; 4 : the 20th day ; 5 : the 25th day.

Plate II.

Plate II. Showing the appearance of above-ground part of a potato plant at each stage after sprouting. 6 : the 30th day 7 : the 35th day.

Plate III. Showing the appearance of above-ground part of a potato at each stage after sprouting. 8 : the 40th day ; 9 : the 45th day.

Plate IV.

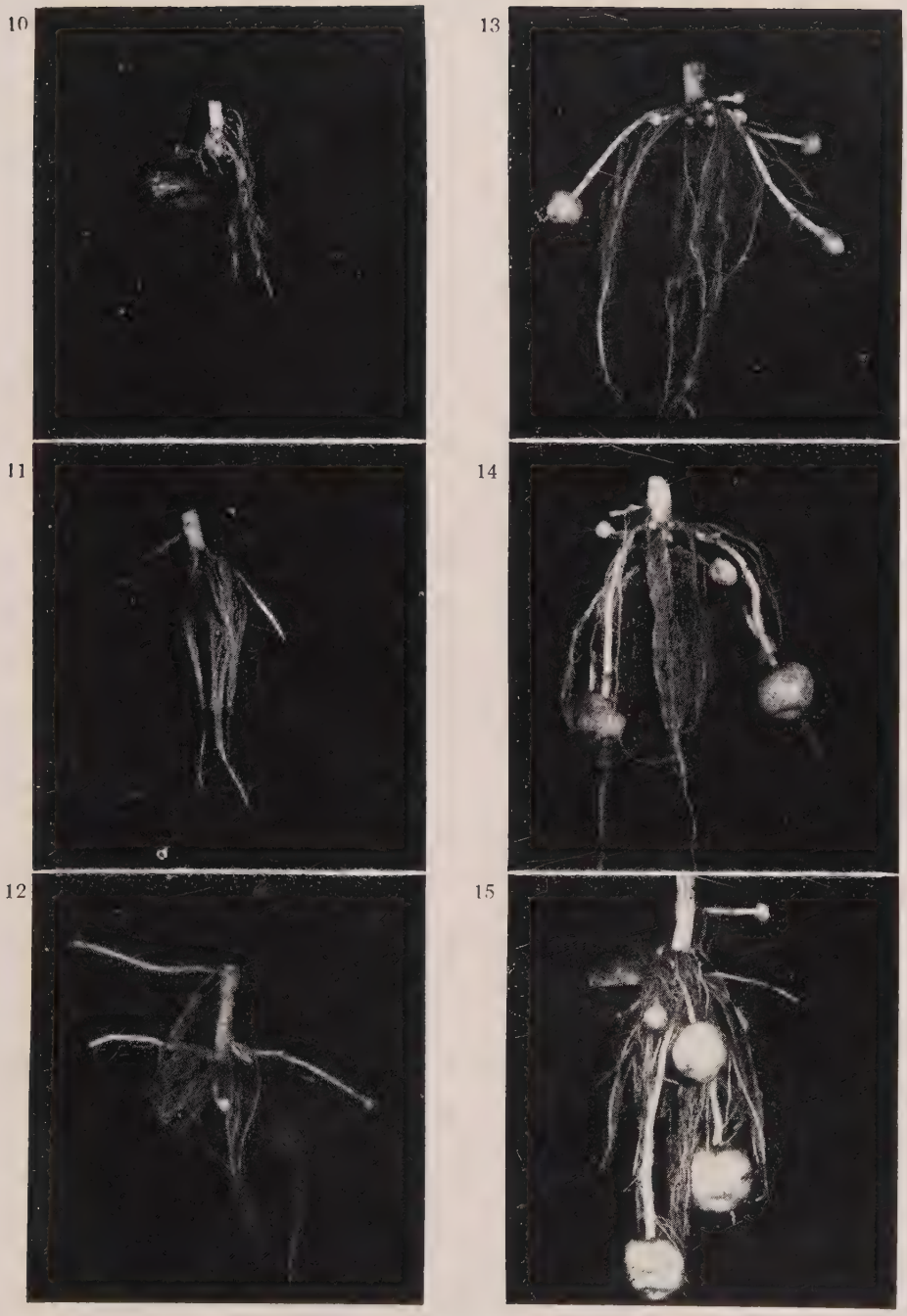


Plate IV. Showing the appearance of underground part of a potato plant at each stage after sprouting. 10 : the 5th day ; 11 : the 10th day ; 12 : the 15th day ; 13 : the 20th day ; 14 : the 25th day ; 15 : the 30th day.

Plate V.

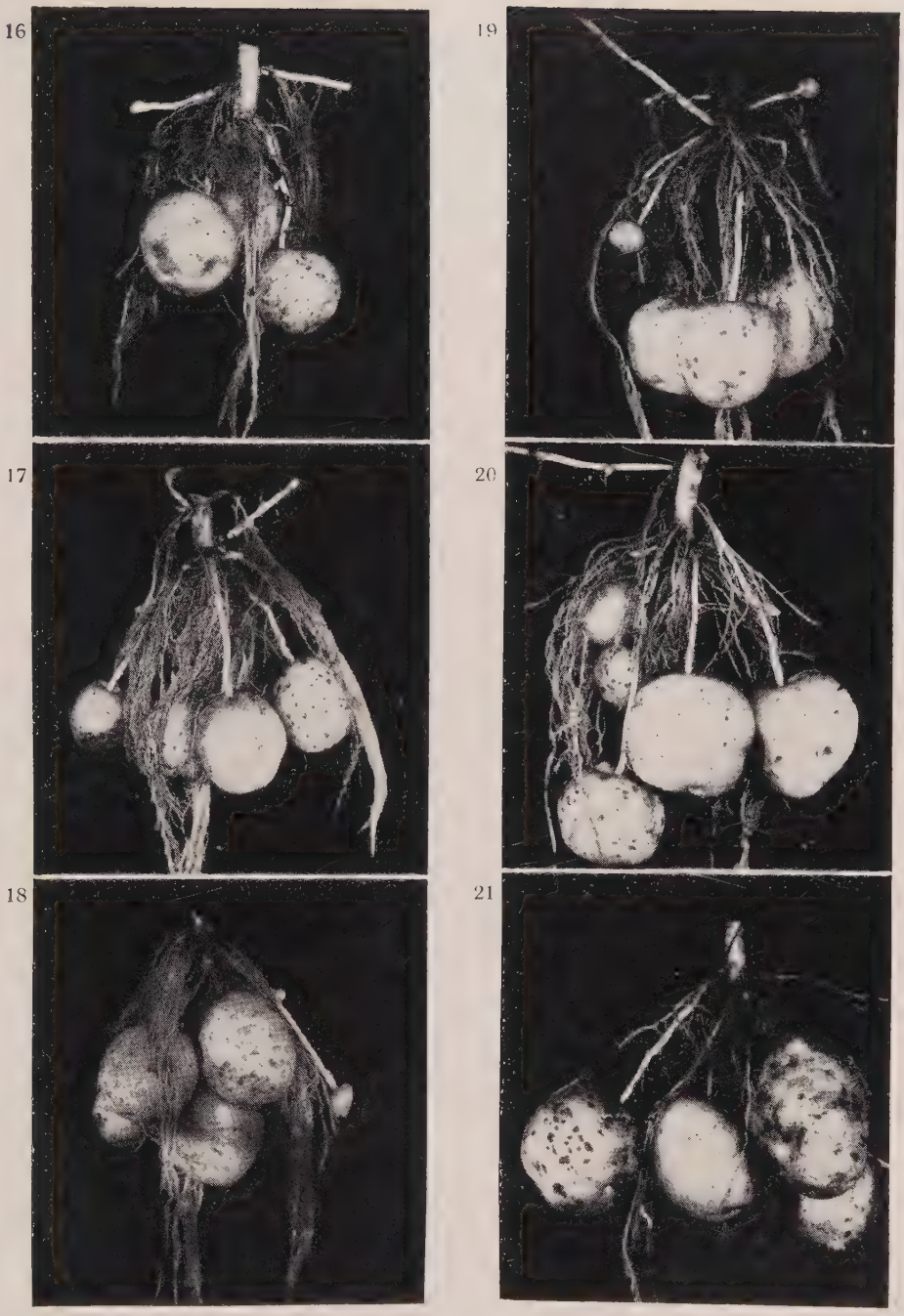
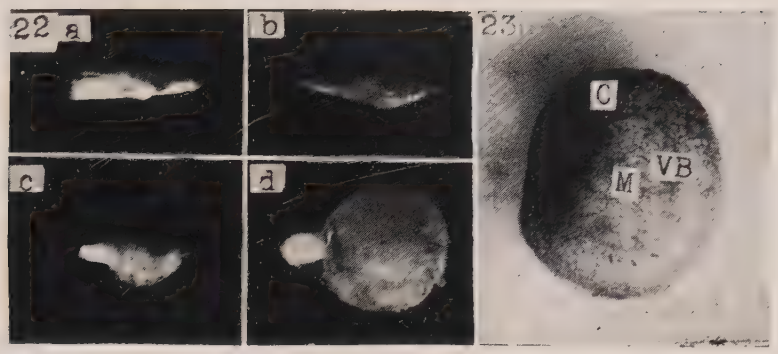


Plate V. Showing the appearance of underground part of a potato plant at each stage after sprouting. 16 : the 35th day ; 17 : the 40th day ; 18 : the 45th day ; 19 : the 55th day ; 20 : the 60th day ; 21 : the 65th day.



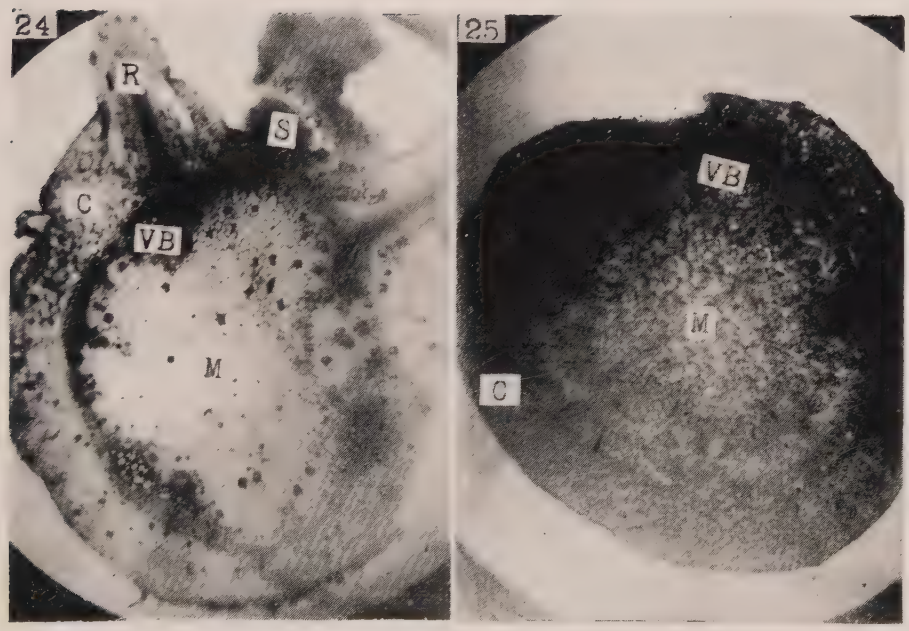


Plate VI. 22 : The stolon tip at four stages from stolon to tuber. a : stage I ; b : stage II ; c : stage III ; d : stage IV. 23 : the cross section of elongating stolon (×20). 24 : the cross section of main stem, from which the stolon is emerging (×20). 25 : the cross section of a young tuber at stage III (×20). C : cortex ; VB : vascular tissue ; M : medulla ; R : root ; S : stolon.

Plate VII.

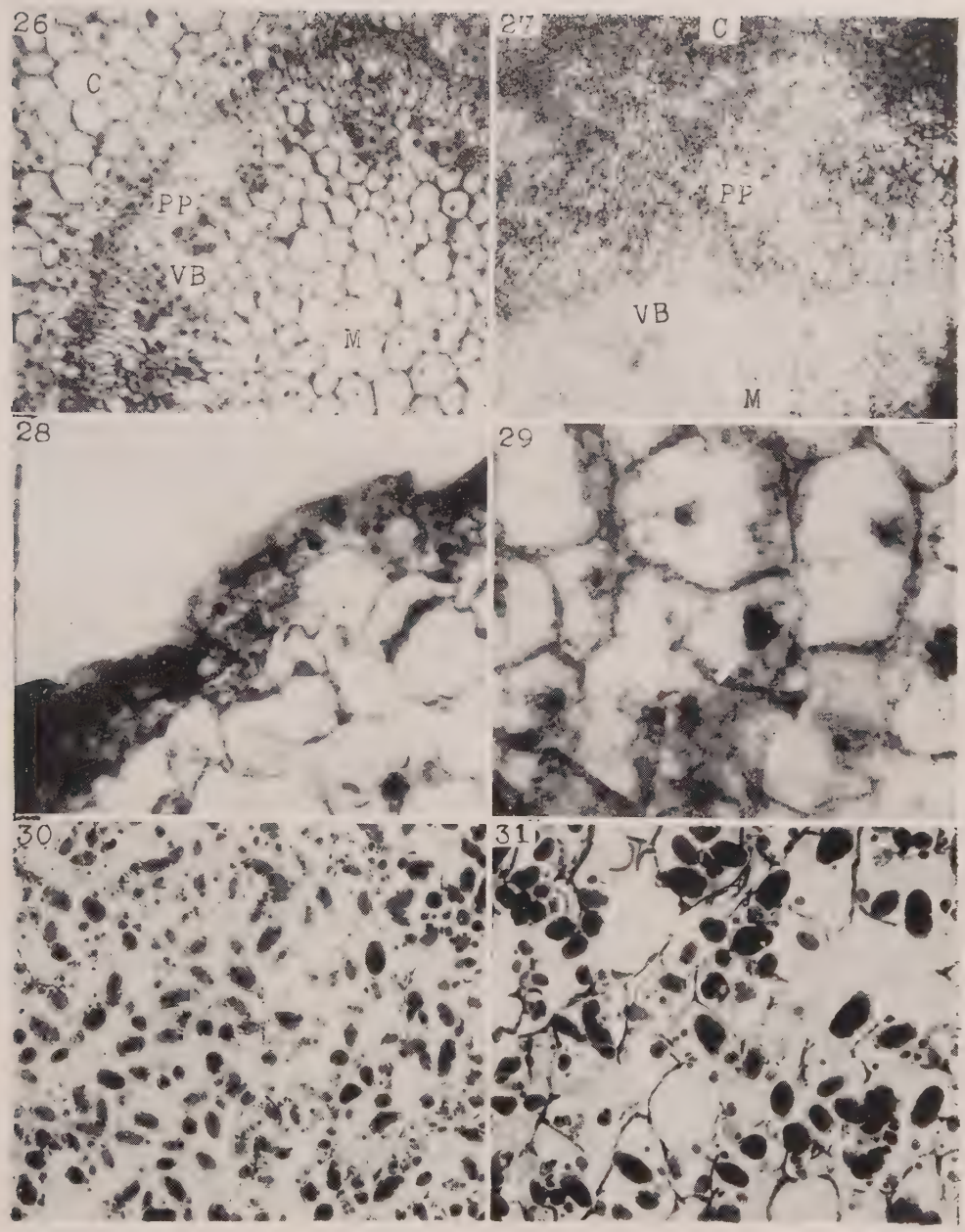


Plate VII. 26 shows development of the phloem parenchyma in stage II. (×200) 27 shows development of phloem parenchyma in stage IV. (×50) 28 shows dividing cell in the epidermal layer, and 29 in the cortex. (×500) 30 shows development of starch grains in early stage of the tuber enlargement and 31 in late stage. (×200) PP : phloem parenchyma.

On the Economic Meaning of the Crop Breeding in the Japanese Agriculture*

Shigemitsu SUNAGA

(Received April 30, 1950)

I. Economic meaning of the variety of crops

Ages it has been a basic principle of all productive activities to get the largest products with the least labor. Needless to say that since labor capacity depends on the human labor paid for the purpose of production, it is a natural human demand to lighten the burden of labor as much as possible, and since the production is the object of human labor, men naturally claim for the largest amount of it with the easiest method. However, these ideas of decreasing sacrifice and increasing profits contradict each other. In spite of this contradiction, why is this principle required through all kinds of productive activities?

Some methods exist to enable it. If one individual capacity exercises some productive labor with the capacity of a definitive level, productive amount will show definitive line. Therefore if we demanded the largest product amount there would be no other way but to extend working hours. In this case, the labor and product amount would merely increase or decrease in direct proportion, and we could not get the maximum product with the minimum labor. However, provided that we might reorganize the labor system from the individual work into the mass cooperative works, or promote it to the labor division system, the productive amount would increase with the same or less labor amount. We could also put out much more product amount in the individual work with less labor under the conditions that we could use improved implements to make the labor efficient or improve the quality of subject matter would make the work more easy. Thus, the method of promoting the labor efficiency might be called "technique" in broad sense.

This principle of mutual relationship between the labor amount and the product amount also holds true in the field of the agricultural production. However, as the farming is the productive activity having fields and crops yield as the subjects matter of labor or means, the natural dynamic influences on the subjects matter of labor bring about various complicated traits of techniques. The fact that the forms of the working systems are not easily reformed into cooperative or specialized systems seem to be the most characteristics of the agricultural world. But it is also one of the causes why agriculture itself must be ruled by the dynamic quality of

* The 48th report of the Institute for Agricultural Research, Tohoku University, (1951)

nature. However we should say that the nature of the crop plants to be bred is the object of production much more strongly influenced by nature than by the social quality of the working system. This is the problem concerning the subject matter of labor itself in the process of agricultural production, and it is quite a different point from the subject matter of the labor of industry than by the subject matter of labor itself which is regulated by its independent activities, its own life uniforming itself with the soils. In the industry, the subject matter of labor has no life primarily ; accordingly, we can recognize that it has no activity of its own. Of caurse, in this case, there is the possibility of damage, spoil or loss of subject matter of labor, that is, change of materials, but it is also possible to prevent it. On the other hand, in agriculture, the subject matter of labor such as crops and livestocks make the ultimate productive purpose out of their own vital changes of growth and development and only through the activity of subject matter of labor, the production is done. Here is one of the difficulties of agricultural technique in this point.

The cause of the more complicated features of the development of the agricultural technique compared with that of the industrial technique consists in the active nature of the subject matter of labor, it is an undeniable fact. Thus it is understood that the agricultural technique has basic characters as a systematic labor means as the other general techniques have it, besides it has special characters based on its nature. Generally speaking, there is no difference between Agriculture and Industry in the respect that both of them would give the largest production with the least labor. Primarily the technique is adopted for this purpose, and developed. But it is possible that the technique may branch off in two directions, one proceed to shorten the labor to the minimum extent and the other to get the largest production. Especially in the field of farming land, harvesting crops complete its growing period. By thrashing, hulling and manufacturing them, we try to develope mechanical technique in order to lighten the labor amount. Even in the process of plant breeding, the techniques are to be improved toward the largest amount of products in the culturing procedures, such as, selection of better seeds, adequate fertilizers, and protection from various damages. The fertilizing, insect control, crop breeding techniques etc. are introduced in agriculture in the forms finely specified, but at the same time general and universal in their applications. As a matter of course, actualization of these techniques on the basis of scientifical background has been enabled depending upon the development of science and modernization of agriculture along with the development of modern capitalism.

In spite of the technique of crop breeding is an important position on the phases of increasing the product amount, it seems that seed improvement activities are raising a larger amount of crop without using any more labor capacity. In this sense it has a special character of technique. This is the technique which merely makes full use of nature in breeding plants, but it also has some importance in giving great influence to the methods of production in agriculture.

Now let us think of the technique of seed-improvement from the economic standpoint.

We may say that as soon as the social life of human being entered upon the Age of Agriculture seed-improvement started. We can imagine that without any scientific studies in case of planning to breed wild plants for the human use, men may have made choice of most suitable ones among those which had suitable shapes and qualities for the purpose. If we seek for the origin of seed-improvement in this period, it is understood that the origin of it existed with the beginning of agriculture. However, though there are many hypothetical presumptions on how agriculture began, we can not say that these presumptions have been clarified in believable ways. Therefore, we must consider the technique of seed-improvement separated from the formation of agriculture. Some real substantial transition of the human beings of the primitive world for instance, as the transformation from the Hunting Age into the Agricultural Age, might be beyond our imagination as to how it went on and how long it lasted. During such a long period of generations numerous kinds of wild vegetables were taken into the process of cultivation, and domesticated for the use of crop cultivation. We can easily imagine this. We might say that during the time of process of domesticating wild vegetables, the human beings were also in the period of transforming themselves from the primitive stage into that of human society.

As the plants are regulated by the rule of evolution, the men themeslves are evolutive. The evolution of the men is the evolution of their social lives. It constantly brings about new demands, and at the same time creates new processes of productive methods. So that, only in the limited field of diet habits, they are complicated and prolific, and only the ability acquiring and producing the food stuffs makes it possible. It may have been tried in olden time to domesticate wild vegetables for human food, but this does not mean, the collection of wild plants, but the cultivation of them. If once plants are cultivated by men, they adapt themselves to their new circumstances, so men may transform them gradually to meet their demands adapting them to the rules of Nature. Consequently, cultivation itself may also be said to reform the nature of the breeding plant.

The nature of breeding plants or their heredities are variated by their own activity, but cultivation will give full scope to the heredities of plants according to men's purposes. Of course it is not simple to varia e the heredities. We should note the natural characters of the plant and make it fit to our environments and purposes along with the necessary protection, selection and fertilization adapt it to its new circumstances. These three factors of environment, heredities of plants and cultivation decide on the yields and that is the substantial purpose of agricultural production within each limit. Out of these three factors, the environment so called natural fertility of the land in the economics, is the natural condition of the soil and climate and so forth, and the cultivation is the agricultural labor including

techniques. The heredities of cultivating plants means their natural characters. We consider their heredities as the subject matter of agricultural labor appearing in the shape of the plant themselves. Thus, the land can be regarded as means of production or subject matter of labor, but in this case, we may consider it as one of the labor means. So that, in general, agricultural labor procedures means the process which works on the subject matter of labor *viz.* cultivating plants using various implements on the land for the purpose of getting a better harvest. We have already mentioned that the subject matter of labor *viz.* cultivating plants, different from other industries, have their own vital power, and are acting and growing in their specific heredilies, and that these facts complicate the agricultural labor procedures. However, when the heredities are definitive, generalized on the definite social standard, and the product amount is stabilized, natural land fertility in the economics may include the heredities, but when some improved seed shows outstandingly increased crop, here comes a problem for us.

The heredities of the breeding plant are known as the variety of the plant. Since the subjects in agricultural production, so-called breeding plants appear with the quality of the variety, we must strive to improve them. Furthermore we can use another method to change the variety itself so as to increase the amount of harvest under the same environment. The improvement of the variety is led for the purpose of raising the harvest amount primarily, but at the same time its purpose includes the improvement of the seed variety and stabilization through cultivation. In this way, the technique of seed variety improvement may possibly decrease the invested labor amount directly, so it has same characteristic as the other agricultural techniques.

The difficulty to illustrate the theoretical characters of economics concerning the seed-improvement of the crop-breeding has a common factor in the illustration of the general technique of saving labor-powers, and at the same time, it is a special, incidental factor of hereditary variation of the breeding plants, or is another specific factor which may be enabled by the total understanding of the nature of the plant. In short, the difficulty is to miss the surplus profit brought about by the improvement of the seed variety, and in the misunderstanding of the separate profit made by the development of the other techniques such as the fertilizing technique.

The general technical definition of Dr. Terao shows that relating to the varieties, the variety means the cultivation material which has a constant specific hereditary factor of the breeding plant under the ordinary culturing method. So the specific variety was made in utilizing the crop yield as the valued after the cultivation. The differences of the varieties of crops will be discriminated at very complicated points such as tillering power, nutrient absorbent power, shape of seed, growing period of crops, the effect of fertilizer, the degree of the reaction to light and temperature, the resistance against the climatic damages and plant diseases etc. The species and differences of these varieties firstly require the specific method of cultiva-

tion and secondly affect on the amount and quality of the crop yield. This fact proves that speciality of the variety will affect the labor capacity, the required amount of fertilizer and other agricultural materials among the essential factors for farming, and on the other hand, it brings out some influence on the farmers' home economy with the amount and quality of the crop.

As it will be possible to breed gradually the varieties which have different characteristics, such as resistence to over-fertility, over-humidity or over dryness etc., some sterile land that used to be inferior as far as men bred old type seed variety, will possibily shorten the difference between natural fertile land and sterile land. That is to bring about the same effect as to improve the land-fertility of inferior lands. Thus, the hereditary character regulating the seed variety does not require any expence on the part of the cultivator, but on utilizing it, it will bring out some profits and expenses. Provided that the cultivating method itself will not be changed or rather simplified, and as a result of that, the crops may be increased, it will be shown as a less sacrifice by taking advantage of the natural power in the agricultural field.

Therefore there is no more desirable technique than the improvement of the seed variety for the cultivators. Especially as agriculture was a hazardous productive activity with laborious works, the farmers have been claiming for less works and for the elimination of hazards of crop yield in addition to the increase of the crops through the centuries. However, this was only a dream and people could not fulfill this in the age when science had not yet flourished.

Different from self-sufficiency of farming in the feudalistic community, improved seed variety costs the farmers seed expenditures purchased at the farm management in the world of modern economy, and the increased income will be withdrawn as a constant capital for the next seed-cost, the rest of it will be the farmer's own profits in the form of relative surplus value. However, if these improved seeds were popularized, and turned over to the social productive power, the relative surplus value of the farm management would be rapidly extinguished and the price of agricultural products should drop down. If it is still maintained by social demands, it may convert to farm rent. The increased crops caused by the improvement of varieties, minus the seed cost, would seem as a gift of Nature, and if it could possibly get the commercial prices, it would be paid by the social wealth. The expenses for the seed improvement would be a constant capital in form of seed-cost, but the rest of it corresponding to a specific surplus value would be brought out by a natural power of hereditary variety. On practising such an analysis, come to the conclusion that the characters of breeding plant relating to the variety may be involved in the idea of natural land fertility in economics. At the Japanese farms which are quite different from those of pure capitalistic societies the problem will not be settled exactly in this way. However, it will made clear that this principle is to be seen every where transforming itself into various types as described in the analysis of the following chapters.

II. The development of the technique of the crop variety improvement

In the unscientific feudal age, the crop variety improvement was completely left to experience and observation. Since it was a desire for the farmer to get a large crop without much labor, it is apparent that they must have tried hard to get better harvests. They knew that some desirable prolific kinds of plants happend to come out from their actual experience, so they used to select better seeds for the better harvest of the following year. Indeed, a great number of diligent farmers had tried to select better seed for long past years. It is a matter of cause that the people knew nothing about the culture of better seeds before the advanced science of the present time. They found only one way of improving seed variety and this was when they noticed the realistic fact of hereditary variation of plants. Since the variation of culturing plants occurred by chance, such chance was very scarce, consequently it had to take long length of time to meet one such variation. Besides, the farmer's skilled experience and observation were required to take advantage of this chance.

Originally, the ideology of the feudal age was an inflexible and formal one. The social system set up the classification of people in the form of almost congenitally unchangeable. So that, the farmers could not be anything else but farmers, and this was fixed in an invariable idea that there was no other seed variety than that determined by God in Heaven. This idea was dominant among the people and prevailed to the exess. This idea was conceived more by the people of the "SAMURAI" class than by the farmers, but the farmers, as a matter of cause could not get rid of it. Yet, they considered that it is the most important duty to choose the best seeds for the best harvest. The following lesson was written in the agricultural manual (NOGYO-ZENSHO 1697) of that age ;

> "To select the best seeds is most important for all breeding plants, not excluded in the Five Cereals (rice, barley, wheat, millet and Indean beans). The seed is the vital origin of living things. As it contains the physical function in it, we should be careful in handling it. Some plants grown up with moderate maturity, good color and shape and not damaged by noxious insects shall be cropped after their complete maturity. Among them female ears shall be picked up. We call the nature breeding plant full of grains on the top and supple stalk, leaves and joints female ears".

Briefly, as the seed regulate the physical function of plants, the farmer should take the most prolific seed, so-called female ears. (see note 1) He need not take variated seeds but he must select the best qualified for the purpose of cultivation. In this agricultural manual of Genroku Era the idea of "female ears" was prescribed. In the mean time, in another book of the same type called SEIRYOKI (1563) 130 years older than the former, we find, the following description.

"All kinds of seeds for farming used should be cropped in time, paying great

attention to the grain maturity, dryness of husks, or wetness, and take great care of the plants not to expose them in cold places and to keep them in good condition. If you have good seed you won't have bad harvest, if you have bad seed you will never have good crops."

In comparison with SEIRYOKI, in the latter we see much more improved observations on good seeds described; but primarily these two books had the intention to teach the farmers how to select more suitable seeds. Thus we can presume that the major agricultural guidance book stressed on teaching people how to select the seed-plants suited to the purpose.

Note 1 ; It seems to be a popular idea to pick up female ears of plant for use of seed. In the AIZU agricultural text (1684) also, we can find such a resemble description. "An old farmer says that there are two types of rice plants one called female ear with broad well-grown leaves and the other is male which has thin, needle-like leaves in their sprout. After the growth of grain, male plants bear small grains, so this field of male-plants will yield a small crop of rice. They say, when you select seeds, you must avoid male grain by sifting. But I do not believe it, for I have never made the experiment of it."

The above mentioned description quoted from the text is rather vague but is only a kind of theory on the seeds. And it shows a method of variety improvement in form of seed selection method. But I presume there must have been more complicated improving methods to adjust one specific nature of plants to the specific environment. In general, the seed-improvements are to be achieved in the specific area or specific farming community, that is, in the area which has about the same environmental conditions, it is also done for the purpose of improving the varieties of crops in order to get the best quality of the variety for different areas. This method must have been performed unconsciously for long years past. For example, it is said that rice-plant originated in India, but it was transplanted to the Southern part of Japan in olden times, and has been cultivated gradually expanding towards the northern parts into Tugaru region (Aomori Pref.) since 300 years ago. It possibly seems to be a phenomenon which occurred along with the emigration of the population, and the fact that rice-plant was gradually transplanted towards the northern region is apparently a good result of seed improvement by adapting the nature of plants to the new environment. As the environmental conditions include all climatic, siol and other numerous conditions, it is not difficult to imagine that it must have taken a long time and laborious efforts to adjust the variety into so complicated farming environments which is made from complicated geographical aspects of this country. In spite of our long agricultural history since olden ages, we have not yet found out the record described on how these adaptation of the varieties were done. We can only say that it is the result of streneous efforts of farmers who had no letters through the past generations.

In the NOGYO-ZENSHO, one of the agricultural monuments in Genroku Era (17th century) the following quotation is read;

"In addition to the indigenous varieties of crops, you should also try to

cultivate the new varieties which are sought for in other areas. You had better pay good attention to them, because among the same sorts of crops there can be found some of a very inferior quality. Even if a kind of crop is an exellent plant in some particular area, it may some times not grow up in another area, though such a case may seldom happen. Naturally some plant can not grow up due to the different climatic condition. It is no wonder that the mandarin orange trees, the ginger, the tropical bamboo were never grown up in northern snowy countries. The difference of the lands in latitude, temperature and adaptability of seeds to the soil can not be changed by human power. However, despite the above mentioned difficult conditions, we can change and improve the breeding plant varieties with skilled techniques and good devices and cares, to great extents, so we should try them constantly and seek for more profitable crops."

From various angles, we are interested in this quotation, and especially as an application of seed-improvement method. The use of regional and environmental condition of arable lands, attracts our attention. Since most of our farms were managed in a self-sufficient manner, it is understood that the farmers emphasized on crop breedings for their own foods, subsequently the staple food plants were given good adaptability to the specific environment with the farmers' efforts through the past generations.

However, for the self-sufficient management of farms, all kinds of breeding plants to satisfy the requirements of farming lives, such as, plants for the use of textile, edible oil, dye, and medicines must be cultivated in order to meet the living demands of farmers' daily lives. As a matter of course, the farmers' living standard has to maintain its low level stage as far as the agricultural technique is kept in such low stage as not to be able to give their culturing plants adequate adaptability to the soil, but along with the improvement of living standards, the farmers' efforts towards the seed-improvements will be strengthened gradually. So to introduce these breeding plants into their own lands, they must transport them from other areas where there are different environmental conditions, so they need to adjust these improved plants to the new environment to give them new adaptability.

Thus, a great number of breeding plants were given newly adaptability which suits each region or district. Perhaps, thus they were cultivated after the careful study of breeding method and selection of better-seeds "with skilled techniques and good devices gradually" eliminating the exceptions which "can not be changed by human power". In the early stage of the feudalistic period, as the efforts toward the larger amount harvest were done to satisfy the requirements of self-sufficient farm management, the variety of crop was limited by itself to the extent that the farmers could be satisfied with their living condition, that is, only the most necessary varieties of crops could introduced, transported and inproved for the farmers even though these procedures took long periods of generations, but the other plants were neglected as they were because the farmers were satisfied with what they had and

did not care for the others.

However, time came when the commercial economy had come to throw some influence on the farms. They had to prepare to sell the crop even under the feudal society, when they would probably come to fail to run the farms only depending on the self-sufficient farming. Here was the new chance for farmers to bring in the new profitable plants. Probably the quotes from NOGYO-ZENSHO above mentioned agricultural text may mean this fact in the following sentence of "Seek for profitable seeds of crops and cultivate them." It is evident that since Genroku Era commercial economy had come into our rural community, and this fact is understood from the seed-improvement angle. Briefly, the crop variety improvement was done for the purpose of living security by means of cautious cultivation of selected seeds of crops by human experience and observation as a basic knowledge. Then as commerce began to spread into the rural communities, the profitable seeds of crops were transported from one place to another and were bred with strenuous physical labor and efforts. To conclude, we may say, that the seed-improvement was achieved then. It means that the economic relation of commodity took a role to stimulate the crop seed improvement.

However, it is an undeniable fact that only the seed-improvement of the rice plants were emphasized in our country. It seems to us that the self-supply system of food in the farms on a small scale caused the fact. On the other hand we also see that the feudalistic social system which required our farmer to pay heavy tribute with their rice products only, stimulated them to get the largest crops from their small arable lands. The intensive agricultural labor is done by several individuals who work hard and with fertilizers which must be gathered and stored up. Every kind of fertilizer, such as human manure, mud and dust are used on the farm lands. This type of farming system was formed by itself and thus, the crop-seed variety adapted to such specifically formed lands had to be bred. That is the reason why such a research for seed-improvement in our country was to lay stress on the rice plant in accordance with the factors of farming system, of fertilization and of the laborous hand work. In view of the social situation of this farm magnaement and system, it was possible to maintain a fairly high tax payment level. On the other hand the higher rent for the lands with their part of rice-crops invited the improvement of varieties of rice which brought the largest amount of crops and showed flexible adaptability to the complicated climatic and soil conditions. Finally, the fact shows that the technical effects of seed-improvements rose the natural fertility of the land and accordingly rose the farm rent automatically, that is, even under the feudalistic farming world, we can find the same obscure beginning of the principle of modern society.

It has been already made clear that seed-improvement centered around the rice plant which was our staple food stuff, and is the advantageous means paying feudal tribute and farm rent, in our country. As the farms gradually went into exchange

economy with these two characters of farm economy, at the same time, the seed improvement seemed to develope with constant efforts. For small farms which live on self-sufficient system of food and are heavily taxed, seed-improvement must be the most important agricultural technique to get better crops utilizing the natural power which never requires noticiable expenses and labor. A great number of diligent farmers select numerous varieties after observing and experimenting rice plants with remarkable patience and caution. We are told that over 2,000 varieties have been selected among rice plant varieties exclusively. Though these numerous varieties have been bred, their theoretical foundation was not set up until the beginning of Meiji Era, and it has been depending upon farmers' individual experiment. This fact apparently shows us the difficulty of its technique. In Europe, the techniques of fertilization, of noxious insect control, and of agricultural implements and machinary have been much improved since the Industrial Revolution was completed, along with the development of chemistry, dinamics and optics in the cities. However, scientific progress of seed-improvement technique was stagnant for a long time even in European countries. Because in Europe the burdens of feudal tributes on farmers were not so heavy as those in Japan. This fact seen from another angle, here lies the difficulty of theoretical heredity.

The diligent farmers in feudalistic ages could not establish systematic seed improvement techniques scientifically, because they could not find out the theory of fertilization and maturation of the plants. In the old Agricultural Manual (NOGYO-ZENSHO) difference of male and female ears of rice plant was refered to and in another text of AIZU-NOSHO, the auther states a negative opinion against discrimination of male and female ears. However those statements are not based on scientific recognition. Even in European countries, it took thousands of years to prove clearly that the pollination is indispensable for the fruit-bearing of plants. It had not been made clear until the end of the 17th century, until Camerarius discovered the physiological function of pistil. The Industrial Revolution that began to proceed during the first period of the 16th century in England, exerted its influence upon the countries of the European continent. This experiment by Camerarius was continued by many nations since the beginning of the 18th century. In the latter period of the 18th centnry, Kölreuter succeeded the hybridization between different varieties. He also explained the relationship and character of hybrid species by his constant observations in the form of almost exclusive systematic theory. But it was in 1884 that the theory of hybridism advanced to the extent of clarifying the germination process of plant in the physiological function, by Strasburger's successful researches. Until then, many researches were carried on, and in 1865 Mendelism was completed. However, as we know, Mendelism was not approved untill 1900. And in 1903 mutation theory by DeVries and theory of the selection within pure line by Johansen were discovered. Therefore we can say that scientific crop-breeding methods were recognized from the end of the 19th century to the early period of 20th century.

Then scholastic research of heredity began to be applied scientifically on seed-improvement. The greater part of the revenue of the first Japanese central government in the early stage of Meiji Era depended on the arable-land taxes. However it decreased gradually later on. Yet untill the 30th year of Meiji (1897), the capitalistic industries had not set up. Accordingly rather heavy burden of annual revenue was borne by the farmers. Japan had been exporting her rice product up to those days, but since then, it showed a tendency of changing into a rice-importing country. While capitalism progressed we could not reform the agricultural management owing to the delay of capitalism. So the farmers maintained numerous farms on a small scale. But the influence of the commodity exchange economy began to penetrate deeply into the villages. When Japan began to import food, she met with the economic difficulties of countless farmers. The national government was obliged to take a policy towards the maintenance of these farms by having them yield large products from their narrow farm-lands. During this period, amature specialists of seed-improvement succeeded in cultivating excellent varieties of rice plants, although their methods had nothing different from those of the feudal ages. The idea of hybridism of plants was introduced in 1891 as a theory in our scientific world, but it was by the end of Meiji Era (1910) that it was actually applied as trial experiments and was made a success. When the first agricultural experimental station was set up in 1893, the agricultural engineers put stress on the research and study of comparative test of rice product on the amount of each variety, and on surveys of special characters of the best cultured varieties up to then. These researches were continued up to 1910 by the agricultural engineers of the experimental station. Best of all Mr. Taketa and Mr. Kato's surveys were so much profitable that they utilised a great background of seed-improvement later on. In 1906, Mr. Moho Kato tried the hydridization of the rice plant at Himezi Agricultural Experimental Station. In 1910, Mr. Hiroshi Terao used the method of selection within pure line at Ohu Experimental Station as a first experiment of scientifical seed-improvement. The latter showed high effectivness in selecting pure varieties of rice out of the numerous old varieties, and accomplished his aim through the period of Taisho Era (1905–1925). For the hybridization of rice plants, as provided in the testifying organization of hybrid species issued in 1910, all the central and local experimental stations made full use of it for the expansion activity of hybrid species. As the price of rice crops rose up gradually during Taisho Era (1918–1927), researches of rice plant heredity were promoted to the stage of analysis of heredital factors, and the efforts towards increase of rice crops and the improvement of its qualities and other details were studied.

After the economic prosperity of the Taisho period, the depression came through the years of Showa, when Japan faced the Manchurian Accident, the China Accident, World War II. Production of fertilizers had been in prosperity through the Taisho Era, so the farming method through the fertilization system had become

very good. In this period, due to the overproduction of rice, the researches of seed-improvement of rice were centered around the breeding of varieties of good taste. But when the War broke out, food shortage occured in Japan. Then the tendency was emphasized on breeding varieties of larger yield. Since 1926, an organic crop breeding system for the seed-improvement was established all over eight districts throughout the whole country. According to this system, the first operation of crop breeding, cross-operation, and selection F_2 plants were operated in the central experimental station, the selection of F_3 etc. plants and their stabilization were to be operated at the local experimental station of each district. The excellent varieties which were bred up in each branch station were distributed in whole districts and given as examples of improved seeds after the local tests. As a result of the efficiency of this system, the seed-improvement activities were to be run as an enterprise of national central government.

The seed-improvement techniques of this period became very unanimous, and at the same time along with our complicated climatic conditions and farming conditions, progressed towards the concrete, practical trend of plant breedings. The aim of rice plant breeding for the farmers must be to aquire the plant which comes to a convenient maturity and good quality, and this aim will be concretized to fit complicated economic environment. Now it is made clear that this result of seed improvement played a master role to equalize the natural land fertility. On the other hand, in the selection of original mother plants, the study of the oecological characters of rice plant varieties are required, such studies also were thoroughly done in this period. The productive power of varieties of rice plant in the very different culturing conditions being made clear, the results were also applied on seed improvement. The seed-improvement technique taking advantage of the exact knowledge of physiological trends of rice plant got clearer year by year since the beginning of the Showa period. For instance, the study of resistance against plant diseases, especially of blast disease of rice plants showed much progress, its difference due to the difference of varieties was made clear to some extent. As for the damages by noxious insects, a test was carried out on the resistance against damages of *Chilo simplex* BUTLER, etc. for rice plant of Indica type and of Japonicas. Accordingly there seemed to have been some advance in this study. Besides this, cultivating methods change according to the character of newly bred varieties of rice plants. For instance, we are told that the difference of sowing density in rice seedling-bed, the quantity of fertilizers, and adaptability of seed to the land can be figured out between early and late varieties of rice by observing the reaction of seedlings, and so on.

The purpose of improving the variety of breeding plants is to secure stable and large crops and to improve the quality and profit. However the latter purpose would rather have to center around the improvement activities for commercializing farming products. But in our country, the greater part of seed-improvement

activity was played by the feudalistic self-sufficient farms in olden time, and since the Meiji period, the national government made the major part of the activity, therefore, it did not show a regular form of development for the requires of market agriculture. However, as far as the plants of staple foods are concerned, the aim of seed-improvement was really changed according to the governmental political requirements. In spite of the above mentioned fact, it is also undeniable that the seed-improvement was exercised to help raise up the market value of rice according to the transient situation of demand and supply, and of marketing process of rice crop. In spite of this commercial influence, however, it is apparent that our farming crops centering on rice products increased through the scientifical techniques of seed-improvement. It means that our technique performed an out-standing role. The present amount of rice products per *cho* (ca. one hectare) shows twice as much as that of the earlier period of Meiji. But this is not due to the technique of seed-improvement only. The variety itself means the character of inner quality of the breeding plant, and the crop is brought forth by mutual limitation of cultivating and environmental conditions. Therefore fertilization, method of ploughing, sowing and breeding each have something to do with the crop brought forth. The result of these appears in the crops. Accordingly, an increase of crop will be due to the technical standard. However there is no way to figure out exactly how much, nowadays, the amount of increase is seen by the seed-improvement technique, though experimental studies are being made about it. According to Dr. Hiroshi Terao, the effect of the breeding technique of rice plant is shown in Table 1.

The result of experiments on 261 varieties by selection within pure line shows 9 percent of average increase, and hybrid species shows 16.2 percent average increase among twelve varieties. As this survey was done in 1931, the present percentage may possibly have been improved. It is a remarkable effect that the crop increase shows 16.2 percent for twelve years since the scientific seed-miprovement technique has been put into effect in 1907.

According to Dr. Terao's method, the increase amount of the staple food cereals is shown on the Table 1. These varieties of rice in the table are representative. The maximum increase of these newly improved varieties was 0.699 *koku* per *tan* (1 *koku*=ca. 5 Bushel) compared to the standard varieties' yield. Generally speaking the improved varieties in the Tohoku region showed a higher increase. From technical standpoints, these situations proved the big effect of seed-improvement. Even though these improved qualities of the variety are not actually utilized by the farms at large, it is undeniable that crops increased as a result of seed-improvement. As a matter of fact we understand that this crop-increase rate was accompanied by all general techniques including fertilization management, farming condition and natural environments etc. that is, in this case all the characters of good farming were compound. It seems unusual to us that the effect of seed-improvement is remarkable in the Tohoku

Table 1. The increased yield by newly bred rice plant.

Name of bred varieties of rice plant	Prefecture	Yield per *tan* (*koku*)	Standard variety	Yield per *tan* (*koku*)	Increased yield per *tan* (*koku*)
Rikuu no.132	Iwate	4.017	Wase-ono no. 1	3.362	0.655
no. 42	Akita	2.758	Kameno-o no. 1	2.059	0.699
no. 71	Akita	2.385	Sekiyama no. 7	1.981	0.404
no. 43	Gifu	3.033	Shima-bozu	2.673	0.355
Kinai-wase no. 58	Fukui	3.091	Shiota	2.565	0.257
no.157	Nagano	3.201	Average of 14 varieties	2.609	0.592
no. 22	Shizuoka	2.673	Aikoku	2.260	0.403
Kinai-oku no. 4	Shizuoka	2.781	Shinriki	2.427	0.354
Nakate-Shinriki	Shiga	3.095	Shinriki	2.710	0.385
Wase-Goriki	Saga	2.894	Homasi	2.563	0.331
Kinai-nakate no. 4	Kumamoto	3.140	Kumamoto Nisenbon no.3	2.285	0.395
Kyushu no. 8	Kumamoto	3.240	Shinriki	2.806	0.434

region where natural environmental, climatic conditions are most inferior. However, this fact proves the fore-mentioned logic that from the economic standpoint, the technique of seed-improvement finally aims at raising the fertility of the land and is utilizes and makes even the fertility degrees of arable lands. (see note 2). It is also clear just as I mentioned that the variety can possibly be promoted and that the real indispensable, practical qualities, depend on the breeding techniques, which mean qualities of labor.

Note 2 ; As a result of seed-improvement, we can see many instances when lands of inferior quality yield more crops or complete sterile lands begin to produce crops. For example, until 1935, the northern limit of rice plant culturing was the Kamikawa area of the Hokkaido region, but since the new varieties named Norin no. 9 and Norin no. 11 have been bred up, and the ear-sprouting season of those two varieties are earlier than others, *i.e.* the middle of August, rice plants have been planted at Kitami and Fukami areas which are located at way up north. Since then, about 2 *koku* per *tan* (1 *tan*=about 0.25 acre) have been produced around there.

Speaking of wheat, it was impossible to cultivate this plant on the snowy, mountainous areas around the boundary of Akita and Iwate prefectures, up to 1933. But since a variety of wheat, Norin no. 39 was bred at Iwate Agricultural Station in 1939, wheat planting has been accepted as profitable also around Tayama, Arasawa, Yuta, Sawanai areas. Along the sea coast zone connecting Miyagi and Akita prefectures due to cold moist, winds blowing from the sea, the rice paddy yield has frequently been seriously damaged by the blast disease. However, since then a "heavy-eared" variety Tohoku no. 14 was bred up for the first time in 1937. This variety which can well resist against these bad conditions is approved. The rice paddies around this area have yielded much more crops. Another example : since Norin no. 1 a rice plant variety has been cultivated by Mr. Kawakami, Engineer of Niigata Agricultural Experimental Station in 1933, even in cold and humide areas, Niigata, Iwate and Tsugaru district of the Aomori prefecture have been able to produce earlier rice crops which are much better in quality, amount and taste. As the above mentioned facts prove, if we could cultivate some variety having

strong resistance against unfavorable natural conditions, they would prove effective as the land adjust its natural fertility as far as the crops are concerned.

Thus, in view of the technical development of seed-improvement form a social standpoint, it appears in form of making high the natural land fertility, but it does not only equalize natural conditions of regions, but bring forth a better technical standard of the whole community. That is why the community as a whole can not help having increased crop. Consequently, seed-improvement is to appear in form of a general increase of the crop amount for the whole community making even the regional difference of natural environments along with the general progress of agricultural techniques. In regards to this respect, Professor Noguchi made up an interesting statistic shown as follows:

Table 2. Index number of the development of rice-culture.

Periods	Percentage increased I period=100			Percentage increased in successive period.		
	total yield	area sown	yield per *tan*	total yield %	area sown %	yield per *tan* %
I 1886—1891	100	100	100	—	—	—
II 1892—1905	107	104	102	7	4	2
III 1906—1915	131	109	120	22	5	17
IV 1916—1925	148	115	130	13	5	8
V 1926—1935	154	118	131	3	3	1
VI 1936—1940	169	118	144	9	—	10

At a glance at this statistic table, we can see the raise in the total crop index at III (1906～1915). In those years people just started put lime nitrogen into production. The farmers began to use it, therefore this increase seemed to be due mainly to the chemical fertilizer.

At IV (1916～1925) of the table, we can see a considerable ratio increase, and this proves that prodcution of ammonium sulphate advanced in this periode long with the increase of the imported potassium sulphate and calcium superphosphate. In the field of variety improvement, "Selection within pure line" was almost completed, and it was also about this time that artificial hybridization was progressing to some extent. In the period of VI (1936～1940) there was remarkable increase of products. This augmented crop "can be attributed to the well-planned seed improvement activity which has been achieved since 1936" (mentioned Prof. Noguchi). It is very interesting that this nation wide effect of seed-improvement is made clear in the chronicle. In the period III and IV shown on the table, yield per *tan* of every period is increased, but on the other hand, the increase of the area sown is fairly low. This fact proves that increase of harvest depends deeply on intensive agriculture and not much on the extention of arable land.

Seed-improvement developed evenly the crop amount regionally, and raise of technical standard increased the nation wide rice crop amount. But it is not realizable that all the breeding plants throughout our country are bred from excellent

varieties cultivated by a scientific method. Looking into Professor Noguchi's statistics, we find that the area newly sown with a cross breeding variety showed below 10%, while the land sown with seed bred by selection within pure line appears to be 34%, and the rest of sown land used old types of rice seeds in 1934. In the meantime, according to the statement of Mr. K. Matsuo in 1946, the percentage of the hybrid species of rice sown showed 46%, while that of selected seed within pure line was 23%, namely, 70% of the whole arable land was filled with scientifically bred varieties of rice, the rest was sown with old type varieties in 1942. However, these old type seeds were also selcted and improved by the hands of farmers, that means, because of their adaptability to the environmental condition, or because of their prolific characters, they could survive among scientifical hybrid varieties of rice, supplementing the weak points of newly bred rice seeds.

As shown in the above mentioned paragraph, the aspects of effectivness in raising production increased the product of 16%. Speaking of period, since the beginning of Showa Era (1924～1951) rapid effectiveness has come out. Then, about the time when the Pacific War started, the improved seed were sown on over 70% of the whole farm land. Technical research of seed-improvement and its organization was run by governmental means, which fact shows quite a different situation from other advanced foreign countries. It may be attributed to our special social conditions when economy stood on the scale of small farms and destroying civilization in rural districts. In our country, farmers on small scale could not have spared farming products to sell, because they had to keep most of their crops on hand for the daily use of their own families. Consequently available crop amount as commercial goods could not help being extremely small. Here are the difficulties on the process of commercializing small scale farming. The measure taken to solve this difficulty was a very strong one. Briefly, it was to try to get the largest crop amount per *tan* (note ; about 0.25 acres). Primarily our agriculture which was intensitive since the feudalistic ages became comparatively highly taxed (in form of crop) levied on small land, besides, farmers had to support large number of family, they tried to get much more crop amount by investing over working labor. As farming villages were getting commercialized on, farmers had to have farm rent in form of crop instead of tax levied by a feudal lord, and still they had to support the large number of family. Furthermore, they needed to purchase commercial goods at their own expense. To get money, they had to sell more products, to sell more of them, they had to increase their products. In order to increase products maintaining the function of a small scale farming system, they had to use much more fertilizer and improved seed variety. Fundamentally, along with commercialization of fertilizaer, newly established seed-improvement business had to be developed. Manufacturing of fertilizers was done at big industrial factories in our country. However, as for seed-improvement most of its enterprises were kept in the hands of governmental organ except small scale business worked by the crop breeders.

It is difficult to define the reason why the crop-breeding business was not taken as a free capitalist enterprise, but probably it seemed to be a nature of crop-breeding business and a political viewpoint of our central government. For the enterprise of the crop-breeding business, it is necessary to grasp thoroughly the specific characters of the variety through close observation, and then to cross it with another, and to select newly bred characters out of hybrid varieties. Finally it has to be stabilized as a new variety. Moreever each stage of procedures takes one year at least, so that, it takes over seven or eight years until the stabilized new variety comes out, and in order to put it for sale on the market, it must be cultivated on a large scale. Yet our natural land fertility is so compliated that there are various sorts of land such as, low and damp places, very dry lands, places where special noxious insects inhabit etc. even within the same one district. Consequently farming conditions also become complicated. Therefore we have to set up a systematic test of a long standing over a fairly extensive area. Even though huge sums of money and facilities are required for manufacturing chemical fertilizers, the circulartion of its funds is led far more rapidly than that of the crop-breeding business. It may fail to succeed as an enterprise, or if it does, it does not pay unless the seeds of bred varieties are sold at extremely high prices. If crop breeding can be practised as a free enterprise, it is natural that the people lay stress on the profits, so that it is likely to happen to lose strictness of scientific procedure, and probably uneducated farmers are apt to fail to grasp the right culturing method for a new bred variety, if it is handled in individual homes. Above all it is probable that the more prolific the varieties bred would be, the more it would be dangerous. If the seed-improvement activity would take such a wrong direction, the downfall of farms would continue endlessly. Eliminating the above mentioned crisis, still they had to get more crops from small farms and the central government desired to put our agricultural system under its guidance. For this purpose, our seed-improvement business had to be administrated by a governmental agency. This was a policy to support small scale farming and we can see there was no other measure except this one. In fact it is proved that the seed-improvement could be introduced in the agricultural field together with the fertilizing products without changing the function of the old farming system. There is a main reason to introduce the technique of breeding to Japanese agriculture. Moreover different from the production of fertilizers, the seed-improvement business has a different aspect in industry, that is, it must depend upon natural environment, and it does not suit to efficient investments, even against these bad conditions. The Japanese people were not wealthy enough to do this. Even as an industry, it has less security. In spite of this disadvantageous undertaking, we are forced to achieve it under a nationwide large scale system in our country. In this regard, we can find the economic meaning of our seed-improvement technique.

III. Farming on small scale and crop variety

We ought to study one economical character of the crop variety from the farmers standpoint. I have already mentioned that our farms on a small scale which have a keen tendency of self-sufficient management, require the largest amount of crop. However,even if this requirement is the same,it can not be considered simply because individual owned lands are scattered separately, and as a result, natural conditions of farm land becomes very complicated. In other words, there are various kinds of soil : clay, damp, sand, peat-bog etc. In regards to availability of irrigation, some places are bad while others are better even within the same dried field. We must select the variety which suits such soil or irrigation conditions. In addition to these complicated condition of siol, climatic condition including those of regional location appear to be indefinite. If it is extremely hot in summer time in some districts, people can not expect the same climate for next summer, it may possibly be cool and damp. If we take those micro climatic phenomena into consideration, numerous changes may happen. To eliminate the damages brought to small scale farms by these inevitable climatic changes as much as possible, we can not depend on one kind of variety which is to bring the largest crop. Therefore, for the purpose of avoiding these dangers, it is a basic counter measure for farmers to adopt early, medium, later crops of rice varieties, changing its ration according to the specific land and climatic condition. Thus, the complicated natural conditions make the varieties numerous, and the self-sufficient farming complicates it. In other words, for the use of their own staple food they cultivate both the ordinary and better class glutinous rices. From the standpoint of farm management, as disconcentration of labor is indispensable, the farmers need to plant various varieties which mature at differ times so as to avoid duplication of farming labors. In other words, the specific farm management condition of farms on small scale which can not help depending upon only cultivating most sensitive plants to the natural influence have driven us to cultivate numerous sorts of seed varities. We are told that there are over two thousand kinds of rice varieties in our country. Even one farm in one hamlet must take at least ten kinds of rice varieties. That is the reason why so many varieties must be bred.

The fact that the improved seed-variety does not reach the goal of complete equalization of so diverse natural conditions, proves that perfect equalization of natural fertility is not yet completed. However, having increased the safety of crops in cold regions, and having increased crop amount, were very useful to stabilize farm management, as well as farm rent.

As above mentioned explains seed-improvement was stimulated with a tendency of emphasize fertilization and commercialization of farming procduts, so that it is apparent that increase of rice crop by means of seed-improvement brought profits to individual farms. Until about the beginning of the Meiji Era, rice yield per

tan (0.25 acres) was estimated 1.2 *koku* (about 6 bushels), at present it has raised to 2.5 *koku*. This improvement on figures ought to be attributed primary to the advanced fertilization and seed-improvement. These two essencial factors of agricultural production have a common trend which could permeate into old type of farming system with modern techniques, and also they are in close relation to have advanced in parallel with each other. The promotion of chemical fertilizer production spurred seed-improvement activity forward, seed-improvement also stimulated complication of the fertilizing method in turn. Generally speaking prolific production of fertilizer offered good incentive to breed the variety having resistance against over-fertility. The technical speciality of these two producting factors are common according to the increase of crops without changing noticiably the farm labor amount. Namely, in terms of economics, "by means of additional investment of the same invariable capital," we shall plan to increase crops. As a result, we may get bigger crops which bring us much more income than the invested capital. However, the fertilizers are used once, while the seed will keep a special character of variety for a long time. This is the only difference between them. But in other respects, both of them have a technical difference and may be used at different times. It is possible to use this on farm management under a large scale or a small scale system, but it suits better on the small scale farm management. Therefore, different from machinary or livestocks, calling-in of additional investment for fertilizer and seeds can be done within one circulation period. This method forces any farmer to use fertilizers and newly bred varieties regardless if they be tenant farmers of farm proprietors.

Thus, our small scale farming required numerous varieties of seed for the purpose of the crop increase, moreover, due to the technical specialities of divisibility and of withdrawal of funds within a short period, farmers would ask for it. It easily penetrated into the inner parts of farm management without interfering with any bulwarks of small scale farming. Over-poputlaion in farming villages interfered with the introduction of modern agricultural machines, and self-sufficient farming on a small scale interrupted noxious insect control facilities and insects invaded the villages. On the contrary improved seed, together with fertilizer, opened the way towards prosperity in the villages. This successful introduction of varieties of crops was accepted as a good method which suited intensive agriculture standing on a base of hand work.

The seed-improvement however, finally happened to help the land-owners as well as farmers who got the farm rent by spot rice before the Farm Land Adjustment Law (1947). Furthermore, we should not overlook the following influence which effected the farmers' economies. It is why farmers are earnestly claiming for prolific varieties of rice, just as they claimed for fertilizers for the same reason. The larger the crop amount got by adequate fertilizing and prolific seed varieties, the more was the grains put for sale. As the seed-improvement business kept on progressing,

grains towards the market increased. Then the prices of grain dropped down. We are well informed that the remarkable example of this influence appeared in the early stage of Showa Era. So as to control the price of staple food, the central government suggested farmers to reduce the sowing area of rice plant.

I have already mentioned that the seed-improvement techniques in our country is used by governmental agencies exclusively. Different from supplying of chemical fertilizer in the case of using the newly bred varieties, the burden that individual famrer had to bear was comparatively low. However, the original character of the new system was to maintain poor farms under the small scale farming system. Out of these varieties they select those that are both sure and prolific. But varieties which are both secure and prolific do not always go together they are apt to check and balance each other. On the other hand, the farms badly in need of money, claim for prolific varieties of crops. Because they believe that abundant crops may be more profitable for them. The varieties bred at agricultural experimental station, by governmental agencies did not always satisfy the desires of the farmers. In the mean time, it is not impossible at all to breed new varieties of crops at other places than governmental experimental station. So, any one who wants can do it, and actually it is practised among amatures though it is on a small scale. In this case, as a matter of fact, various varieties of having a prolific nature, or strong registance against over-fertilization etc. can be expected to appear, but especially, the prolific ones meet with the farmers requirements. It causes the appearance of the so-called "variety in fashion" to propagate these varieties, and then popularize in a short time. This fact shows the farmers' financial difficulties.

The varieties of crops spread in this way often don't have security for the specific weather conditions. Even those excellent varieties bred by the governmental agency passed strict examination and test, may probably encounter disasters which were not taken into consideration. In such occasions, even varieties which have a very prolific nature may give a low crop. In this way, the crops are to decrease inversely opposed to the farmers' fervent intenstion, and individual farmer's finance is to be menaced.

In the above mentioned paragraphs, I have mainly considered the varaiety of rice plant in writing this academic report. Speaking of other farming crops such as wheat, barley, soy-beans and other vegetables, basic economical characters of seed-improvement do not differ much from those of rice-plant. Seed-improvement for these farming plants is not really conducted so systematically on a large scale as that of the rice-pants is. But due to this fact civilians' breeding activity is rather activated on the contrary, and sales of seeds and seedlings spread in an extensive area. As this activity has a close relation to the market crops, the seed itself usually becomes a pure merchandise. It goes without saying that many self-sufficient farmers are likely to utilize the seeds which are selected and reserved out of the

grains for their own consumption, but it takes time to select seeds. Moreover home cultivated seeds are liable to be less productive, they have come to depend on purchasing seeds as commerce developes. As for the fruit-trees, specific techniques being necessary for grafting or breeding sapling, beside required for good quality of fruits, most of fruit gardens must keep an excellent variety of fruit-trees. These seeds or sapling must be purchased which are to appear as excellently bred varieties after being cultivated. Fruits may rather have a tendency of being commercial goods rather than rice-plant, so the fruit-growers' care must constantly be a good variety of fruits. This is a primary motive of seed-improvement in a modern society, but in our country, as far as rice plant is concerned, the governmental influence restricts its basic natures as commercial goods. It is, indeed a special character of our seed-improvement business that on the point of seed-improvement, rice which is to be a commercial good must first be regulated and restricted with more rigidness than other seeds breeding, and yet this seed-improvement is going on better than others under this specific system.

In general, our farms standing on very small scale, must paid high rice-spot rent before the Farm Land Adjustment Law(1947). They must secured foods for the use of home consumption and then must claimed for monetery incomes since modern commercial economy started to come in farming villages. They have asked for better seeds of rice plant and wheat or barley through the seed-improvement. I mentioned before that the improved seeds were effective to serve the maintenance of our old type farms without spending extra money. This effect appeared farmers and inspired them almost religious desires. It is not rare to see farmers of the feudal ages or other diligent peasants in later periods try to breed better varieties of rice at any cost, even if they had to be thieves stealing well-matured ears of rice plants from other paddy fields. This fact proves an extraordinary zeal for seed-variety breeding on the part of our farmers. At the same time, it also shows clearly the farmers' desperate intention to solve the social difficulty of intensive nature of the small scale farming system by means of seed-improvement hard and laborious labor involved in all kinds of works. They used concentrated fertilizers including human manure, weeds, mud taken from ditches, ponds, ashes and even dirty water after washing. In these conditions consist our farming system. Therefore, it was evidently very hard to breed more suitable varieties for such farming. Moreover, they desired it and claimed for it, and continued to improve their seed variety of rice keeping the old farming system as it was. After exerting most laborious work beyond human-power, if they desired to get bigger crops, there was only one way left to them to do so. This is how it should be done and we should not depend on a complicated reform of our farming system. Therefore the seed-improvement technique may be considered to be the result of concentrated labor and the great quantity of concentrated fertilizers used. That is claimed for and desired as the best way to get bigger crop without more efforts. Consequently, though the seed-improvement technique was built

up by modern science, it does not always mean that it modernized our farm management. The techniques of seed-improvement are put under control of governmental agencies exclusively. The improved varieties of crops exist as a prop of olden style farming system on the part of farm management. Agricultural researches progressed towards scientification, but our agriculture itstelf still remains stagnant.

Due to the above mentioned status, seed-improvement activity did not require such great expenses. However satisfaction on the farmers' part did not always mean the raising of their economical living standard in direct proportion. The sooner the exellent variety spread in general, the sooner the prices became lower, and accordingly it was liable to stabilize the foundation of high farm rent of spot crop, before the Farm Land Adjustment Law (1947) proclaimed. Increase of crop by seed-improvement is a result of gratuitous utilization of nature of breeding plant which Nature provides, so the increased part of crops beyond the seed purchasing expenses can be considered as a crystal of pure natural power. Our farmer's painful daily life made them ask for relief in concentration of the gratuitous natural power. But living conditions have never been improved although the farmer's dream was materialized. For increased crops just replaced the tenant charge of lowering prices of farming products. When people once find themselves with such modern scientific improved seed, it is almost impossible to pull backwards advanced situation of seed-improvement. Of caurse, seed-improvement brought some profits to the farmers. Because of this advantage farmers are driven to claim for better variety one after another. That is the reason why, zealous aspiration for seed-improvement is constantly coming from the farmers of our country.

The agricultural standing of modern society, in case it would be taken as an enterprise, could not but go on quite a different way from the other industries, because it is under the control or influences of specific conditions, that is, limitation of arable land and natural fertility of soil. Therefore if our agriculture which stands on the bases of small scale farm management, still keeps a self-sufficient tendency, there is no wonder, it shall be advanced in uneven, deformed line within the function of our imperfect modern society. In other words, agriculture itself can not reasonably be called capitalistic agriculture. Being aware of the circumstances under which the farmers could not possibly estimate adequately their various farm properties, on the other hand, our agriculture could not help being controled by commercialism. Speaking reasonably of modern society, agricultural techinques should be introduced into farming field through the commercial goods circulatory channel under the limit of evaluation, farming implements and machinary, fertilizers, seeds of good varieties are all coming in as commercial goods. However, after this merchandise entered into self-sufficient farms on a small scale, once it began to work as a factor of the old type technical system, it showed itself with special Japanese characters.

As for the varieties, there might be an apparent difference between the adaptation of modern large farm management and the introduction in to our farms under

the small scale farmig system. The main reason of making up such peculiar difference might be defined as the complicated conditions of general natures relating to the lands and managemental characters of our farmers. Really, while our farms are producing commercial goods a little in the advanced modern economical society the most part of natural economy still remain there. Furthermore, modern techniques on the high level of sciences and industries of large cities put together their cultural influences against the rural districts. It makes farms expensive. The farm products put out by those techniques are not returned as a whole back to the market, but a small part of them is to be put for sale, and part is lost as spot farm rent (before the Farm Land Adjustment Law, 1947) and the rest, the large part of it is to be consumed as domestic use. Of course, it can be said that such a mechanism of economic circulation can not be adapted to the modern technical utilization. But modern commercialism and techniques are trying to go ahead, and to open their ways into the small scale farming even in the crippled forms. Under this influence effected on farms, the farm is gradually going on to a transit form less-self-sufficient trend to totally market agriculture. Finally, however the seed-improvement technique may be a zealous desire of small scale farmers, it will be the main cause to stimulate and spur the modernization of farming villages and the commercialization of our farm products.

Summary

Owing to the intensive agriculture, the crop breeding and fertilizing techniques are known as the most important agricultural techniques in Japan. There is a vast amount of scientific research concerning breeding on a large and wide scale. But from the economic standpoint few studies have been carried out concerning this problem. The author obtained results from the economic point of view, which are summarized as follows.

1. It is the ultimate purpose of all the productive activities to get the largest products with the least labor, but the purpose of crop breeding, which differs from other techniques, is only to get the largest production of crop yield. While the objects of crop breeding are regulated by variable human demands, the technique of breeding stands on a dynamic nature of the physical function of plants. These two sorts of dynamic natures of the technique make the problem of crop breeding difficult

2. It is an authorized theory to describe the technique as a system of labor means, but in this study the author adds to this system the subject matter of labor, which, in the case of agriculture, consists of all the processes of crop growth regulated by the nature of crop varieties.

3. Those farmers of a limited number, who have sown new improved seeds will obtain especially good yield, which brings the surplus profit in their farm capitals. Although these seeds bring good harvest at first, then will soon be

popularized on all the farms, so that the surplus profit mentioned above will be extinguished, and then the farm rent may become high, because the improvement of seeds brings the natural land-fertility in the economics.

4. In the Japanese agriculture the improvement of seed and its breeding have been carried out through the centuries by many farmers on the basis of their experimental skill on farms of a small scale, for they have been charged with the heavy feudal taxes and a large amount of foodstuff for their families. Since the beginning of the 20 th century, the improvement of rice varieties, the main staple food for the Japanese, has been carried out scientifically by the government. Consequently the yield of rice, accompanied by the progress of its fertilizing method, has been about doubled.

5. The economic consequences, which the improvement of seeds has brought to the Japanese farmers, are :

(i) the quantitative increase of crop yield, *i. e.* the utility value, and the relative decrease of crop price,

(ii) the relative increase of farm rent, which has been imposed in the form of spot crops,

(iii) the increase of farm rent in those districts, where the natural fertility of lands is poor such as in cold districts, damp lands, sea coast regions, etc.

On the Logic of Rotation*

Kan-ichi Yoshida

I. Preface

To make clear the essential point of the problem of crop rotation , the way of approach to the problem is important. With a wrong way of approach, we might fail to touch the essential point of the problem.

There are two different standpoints from which we can approach the question of rotation : first, we can take up the problem as that of the natural science, *i. e.*, crop science, soil science, etc ; and second, as that of the social science, *i. e.*, farm management, agricultural economics, etc. Aside from which standpoint is reasonable or proper to start from in approaching the problem, it will go without saying that the way of approach will perhaps differ with the standpoint from which we take up the problem. There are questions which is reasonable way, to handle the problem of rotation as that of the natural science or of the social science, as well as in the way of approaching the problem. Now, a question arises about what is the rotation, or how to understant it. I should like, however, to mention it later and here proceed with our discussion according to the general definition.(1) As for which standpoint should be taken, we can say that we have no choice but to start studying the problem as that of farm management, as far as we take up the rotation actually practised on farms and discuss it, because the natural and social-economic attributes which belong to the crops grown on farms can be observed directly and concretely only within the farm management. I believe, therefore, we can say that it is the most concrete way to handle the problem as that of the farm management. What is, then, the most reasonable way of approach, when we take up the rotation as a problem of the social science, that is, of the farm management?

To answer this question, it is necessary at first to make clear the stand of the crops on the farm, that is to say, to learn about the natural as well as social-economic attributes of the crop. What is the object for a farmer to grow crops on the farm under his management? In the society supported by commercial production system, we must say, cultivation of crops is not the object of itself, but the purpose is to make profits by production. The object of crop cultivation is to make profits according to the economic rationality of the present society of commercial production,

* The 49th report of the Institute for Agricultural Research, Tohoku University. (1951)

and the cultivation of crops is just a means to attain such object. (Self-sufficincy of the crop is put out of consideration just here.) Therefore, the crops on farms bear social-economic characters (or attributes), and, of necessity, the economic requirement for making largest possible profits. On the other hand, crop is a natural existence of itself, and bear natural attributes. But such natural attributes can present themselves only under certain conditions of social economy. In view of this fact, the crops in the farm management should not be observed in their natural attributes alone, but also under social-economic conditions. More concretely, the natural attributes of the crop present themselves under conditions determined by certain stage of science, and, in the farm management, by certain stage of managing technique. The above is a description of the stand of the crop in farm management. Therefore, the problem must be investigated in a way which corresponds to such stand of the crop.

The economic requirement for making maximum profits, which originates from the social-economic attributes of the crop, can not be realized perfectly in actuality and in a concrete way, needless to take examples, because the present stage of the crop science and other natural science or techniques works as a limiting factor. The natural science is understood as technique in farm management. Thus, the economic requirement can not be met indefinitely. On the other hand, the crop has a requirement, which comes from its natural attributes, for natural-scientific or technical conditions of its own. But such requirement of the crop for growth and development, is not possible to be satisfied. This is because, in practical farm management, the social-economic conditions of the farm prevent it. Thus, it becomes necessary to try to observe the crops on the farm in a contradiction between social-economic and natural attributes, *i. e.*, economy and technique. Consequently, the crop rotation, we must say, also should be observed and investigated as a contradiction of economy and technique.

The rotation may also be viewed from another standpoint, that is, how it has been developed, as follows :

As a typical system of the rotation, we must take the Norfolk rotation system developed in England.

This system is expressed as the one with root crops on the first field, summer crops on the second, legumes on the third, and winter crops on the fourth. This system of rotation farming came to be seen in the seventeenth century in England and in the eighteenth century in the continental Europe, and it was in the nineteenth century when it got into extensive use.

Before the rotation system came into existence, the so-called three-field system, which consisted of fallowing on the first field, winter grain on the second, and summer grain on the third, had been used. The three-field system was a farming system adapted to the mediaeval self-sufficient economy, and is not a kind which can go with the society of commercial production. Then, the rotation system has been

developed as a farming system adapted to the modern agriculture in the capitalistic society since the nineteenth century.

Why was, then, the rotation needed in the modern agriculture ?

The rotation is the opposite of the successive planting of the same crop on the same field, and can be described, in form, as planting of one crop after another on each field in a cycle of a few years. What is the reason for such cyclical change of crops? About this, many points have been made clear to date.(2) A reason why the commercial agriculture necessitated the rotation system is found in the fact that, while the market demand for farm products grew rapidly at the time with industrial revolution, want of land had already begun to be felt, resulting in intensified land utilization and expansion in numbers of livestocks (to meet market demand). As a natural results, intensified utilization of land and increased number of livestocks brought about lowering of siol fertility. Here came out the application of manure and the rotation system as means of settling the contradiction between land utilization and soil productivity.

The intensification of land utilization in the commercial agriculture characterized by production for market is aimed at money-making, and shows its social-economic characters, while, on the other hand, the lowering of soil fertility resulting from intensified land utilization represents technical characters.

When we say, "the rotation management enables us to make numberless different combinations of crops to meet the conditions of cultivation and market,"(3) we can understand the conditions of cultivation as technique and the conditions of market as economy.

How is, then, such contradiction between economy and technique shown in a concrete way? It will find its expression in the combination of crops.

In fact, what we can observe on the farm is combination of crops (planting of crops in a more concrete way). Therefore, it can be said that social-economic attribute as the essential content expresses itself in the combination of crops as phenomenal form.

In studying the problem of the rotation, therefore, what can be observed materialistically is phenomena, which are nothing but the combinations of crops. However, such observation of phenomena alone can not make clear the essential of the problem, because, as mentioned above, the rotation is a technique underlying the commercial agriculture and should be observed essentially in the form of contradiction between economy and technique, never being a problem of mere combination of crops. Only by observing the rotation in the contradiction in this way, the combination of crops as a phenomenon also can be understood properly.

In brief, to reveal the essential of the rotaion, understanding not only of the form, as has been the case in the past, but also of the content is important : No, emphasis must be placed rather on the latter. And the study of the problem should be carried out on the course under contradiction between economy and techinque,

and the rotation should also be understood in unification of such contradiction. This means to observe the problem both in concrete phenomenon or form (combination of crops) as well as in essential or content (social-economic and natural attributes). I believe, this is the only way to understand the essential of the probelm of rotation.

II. Rotation in phenomena and essential

How do social-economic and natural attributes of crop, which can be observed in contradiction of economy and technique, present themselves in the rotations practised on farms in actual and concrete conditions?

I should like to show the actual situation on the farms which I researched, for the study of the problem should start with the observation of phenomena. This investigation was carried out in March 1950 on three farms in Namiyanagi-Community, Takarae-Village, Tome-Country, Miyagi-Prefecture: Farm A (141 *se* of paddy fields and 99 *se* of upland fields, totaling 240 *se*: 1st class part-time; owner-farmer), Farm B (110 *se* of paddy fields and 47 *se* 18 *bu* of upland fields, totaling 157 *se* 18 *bu*; 1st class part-time; owner-farmer), and Farm C (47 *se* of paddy fields and 21 *se* of upland fields, totaling 68 *se*; 1st class part-time, owner-tenant-farmer).

The results of the investigation are shown in Table 1. What is to be taken up as a phenomenon and to be discussed here is the facts that all the three farms adopt rotation systems different from each other, and also that differences are seen by field even within each farm.

Table 1. Rotation systems in 3 farms.

Farm	No. of field	Area *se. bu*	1949	1948	1947	1946	Rotation system
A	1	6.25	soy-bean, potato—barley	soy-bean, potato—wheat	soy-bean —barley	,,	two crops a year
	2	24.23	soy-bean —barley	,,	soy-bean —wheat	,,	,,
	3	9.01	soy-bean —barley	soy-bean —wheat	soy-bean —barley	,,	,,
	4	8.14	tabacco	tabacco —barley	soy-bean —barley	tabacco —wheat	,,
	5	19.23	soy-bean —wheat	,,	tabacco, soy-bean —barley	soy-bean —barley	,,
	6	5.15	tomato, egg-plant, water-melon, radish —onion	red-bean —barley	soy-bean	vegetables	,,
	7	17.18	soy-bean, red-bean —wheat	soy-bean —wheat	,,	,,	,,
	8	4.00	grape	,,	,,	,,	,,
	9	3.02	chinese cab-bage, radish —wheat	,,	chinese cab-bage, radish —barley	,,	,,

B	1	5.00	chinese cabbage, radish —potato	,,	,,	,,	two crops a year
	2	8.15	soy-bean —barley	soy-bean —wheat	,,	,,	,,
	3	13.23	soy-bean —naked barley	,,	soy-bean —wheat	,,	,,
	4	7.20	soy-bean —wheat	soy-bean —barley	soy-bean —wheat	,,	,,
	5	4.16					
	6	5.29					
	7	2.05	cucumber, soy-bean, tomato —spring radish	,,	,,	,,	,,
C	1	4.00	chinese cabbage, radish —wheat	soy-bean —potato	chinese cabbage, radish —wheat	soy-bean —potato —cabbage	four crops two years
	2	4.00	soy-bean —potato	chinese cabbage, radish —naked barley	soy-bean —potato	chinese cabbage radish —naked barley	,,
	3	3.00	red-bean, soy-bean, egg-plant, sesame, egoma —rape barley cabbage	chinese cabbage, egoma, cucumber rape —cabbage —naked barley	ston-leek, onion, sweet-potato —wheat —cabbage	soy-bean, egoma, sweet-potato —potato —hemp	two crops a year
	4	6.00	soy-bean —wheat	,,	,,	,,	,,
	5	4.00	soy-bean —naked barley	soy-bean —wheat	soy-bean —naked barley	soy-bean —wheat	,,

Note. 1 *se*=0.9917 are, 1 *se*=30 *bu*.

The rotation system of Farm A is expressed as the system of two crops a year, but the crops are not the same for all fields. Farm B adopts, like Farm A, the system of two crops a year, but the crops are different. On Farm C, the systems of four crops every two years and two crops a year are adopted, and the crops are different, too. It is necessary, then, to know about why these phenomena exist, or by what these phenomena are given rise to. To make clear this point, it will be necessary to know for what the crops are grown on farms, or the object or significance of crop cultivation. It concerns farm income. We can observe the farm income in two different kinds.

It is natural that the farm is under economic rationality as far as it is in the society of commercial production, and, consequently, it can be said that an object of growing crop is to get cash income. This can be shown in Table 2.

According to the table, Farm A got a cash income of 170 thousand yen, which accounted for 60% of the total farm income, from sale of harvested crops. Farm B received 90-odd thousand yen in cash, or 35% of the total farm income. Farm C got a cash income of 60-odd thousand yen from sale of crops, or 60% of the total

Table 2. Cash income classified by source.

Source of cash \ Farm / Tatol	A total *Yen*	A %	B total *Yen*	B %	C total *Yen*	C %
Agricultural income	218.845	78.6	103.555	39.5	78.322	75.0
crops	170.378	61.2	93.165	35.5	63.472	60.8
rice	107.434	38.6	73.551	28.0	42.053	40.3
barley	17.068	6.1	—	—	—	—
wheat	30.043	10.8	3.960	1.5	7.200	6.9
naked-barley	—	—	4.856	1.9	1.324	1.3
soy-bean	4.400	1.6	3.300	1.2	—	—
red-bean	3.600	1.3	—	—	300	0.3
potato	2.483	0.9	948	0.3	—	—
tomato	1.600	0.6	1.000	0.4	—	—
egg-plant	450	0.2	1.200	0.5	600	0.6
onion	1.500	0.5	—	—	—	—
chinese cabbage	—	—	1.800	0.7	5.595	5.3
radish	800	0.3	1.500	0.6	400	0.4
cabbage	—	—	—	—	6.000	5.7
cucumber	—	—	1.050	0.4	—	—
water melon	1.000	0.4	—	—	—	—
grape	5.000	1.8	—	—	—	—
tabacco	17.470	6.3	—	—	—	—
live stock	25.000	9.0	390	0.2	14.850	14.2
others	—	—	10.000	3.8	—	—
Non-agricultural income	8.800	3.2	85.670	32.9	10.600	10.1
labour	2.350	0.8	6.000	2.3	3.300	3.2
other	6.450	2.4	79.670	30.6	7.300	6.9
Income from property	50.506	18.1	72.000	27.6	15.512	14.9
debt	33.000	11.8	60.000	23.0	9.512	9.2
cash on hand	13.000	4.7	10.000	3.8	4.000	3.8
other	4.506	1.6	2.000	0.8	2.000	1.0
Total income	278.543	100.0	261.225	1.000	104.434	100.0

income. It is a common fact for all the three farms that the crops are an important source of cash income, though the amount of such income and its percentage vary. (The reasons for difference in the amount of cash income will not be mentioned just here.) An object of growing crop other than cash income is farm-consumption of products. In the actual situation of the farms of Japan, it is found that substantial emphasis is placed on farm-consumption of the farm products as well as on sale for cash income. How the farm products are used actually on the farms investigated is shown in Table 3.

If we examine the quantity of farm products classified by use for each crop and farm, we can see wide variations among farms not only in kinds of crops but also in quantities by use and in their percentages even of the same kind of crop, resulting in different percentages of farm-consumption and sale among these three farms.

What is to be noticed here is not only the differences in farm-consumption-sale ratio (B C) but also the tendency of great emphasis on farm-consumption, which is common among all the farms.

The facts that the farmers seek the two different objects of both cash income

Table 3. Farm products classified by use.

Crop \ Use / Farm		Consumption for farm (A)				Sale (B)				Grand total (C)	$\frac{A}{C}$
		food	manure	feed	total	delivery	barter	free dearling	total		
Soy-bean (*to*)	A	10.0		8.0	18.0	16.0		26.0	42.0	60.0	70.0
	B	20.0			20.0	12.0			12.0	32.0	37.5
	C	10.0			10.0					10.0	—
Rice (*to*)	A	146.0		6.0	152.0	160.0	8.0		168.0	320.0	52.5
	B	160.0		10.0	170.0	62.0	16.0	40.0	118.0	288.0	41.0
	C	60.0			60.0	40.0	7.8	4.2	52.0	112.0	46.5
Barley (*to*)	A	12.0			12.0	68.0			68.0	80.0	85.0
	B	26.0			26.0					26.0	0
	C	3.0			3.0					3.0	0
Naked barley (*to*)	A										
	B	13.0			13.0	15.0			15.0	28.0	53.5
	C	4.0			4.0	4.0			4.0	8.0	50.0
Wheat (*to*)	A	12.0			12.0	60.0	4.0		64.0	76.0	84.3
	B	23.6			23.6	8.4			8.4	32.0	26.2
	C	4.0			4.6	8.0			8.0	12.0	66.5
Red-bean (*to*)	A	4.0			4.0			4.0	4.0	8.0	50.0
	B	2.0			2.0					2.0	0
	C	0.4			0.4		0.3	0.3	0.6	1.0	60.0
Tabacco (*kg*)	A					194			194	194	100.0
	B										
	C										
Potato (*kan*)	A	128			128	112			112	240	50.0
	B	140		15	155	45			45	200	22.6
	C	80		50	130		70		70	200	35.0
Tomato (*kan*)	A	20			20			40	40	60	66.7
	B	15			15			25	25	40	62.5
	C										
Egg-plant (*kan*)	A	15			15			15	15	30	50.0
	B	20			20			40	40	60	57.2
	C	30			30			30	30	60	50.0
Onion (*kan*)	A	20			20			30	30	50	60.0
	B										
	C										
Radish (*kan*)	A	140			140			60	60	200	30.0
	B	150			150			100	100	250	40.0
	C	160			160			40	40	200	20.0
Chinese cabbage (*kan*)	A	30			30					30	0
	B	60			60			60	60	120	50.0
	C	60		20	80			120	120	200	60.0
Cabbage (*kan*)	A										
	B										
	C	20			20			100	100	120	83.5
Cucumber (*kan*)	A										
	B	15			15		35	35	35	50	70.0
	C										

Sesame (*sho*)	A B C	3			3					3	0
Egoma (*sho*)	A B C	7			7					7	0
(green) Soy-bean (*kan*)	A B C	10			10					10	0
Water melon (*kan*)	A B C	10			10			20	20	30	66.7
Rape (*sho*)	A B C	8			8					8	0
Grape (*kan*)	A B C	30			30			50	50	80	67.7

Note, {1 bushel=2.063 *to*
{1 kg=0.26667 *kan*

and farm-consumption at the same time, as well as that there is only a small difference between percentages of the portion sold and that consumed on the farm must be considered as an expression of the social-economic character which the farm itself bears, of course, under the given technical conditions in which the farm is actually placed.

Now, how such crop income (cash and products for farm-consumption) of the farm has been created, or, in other words, what is the factor which actually regulates the crop income of the farm, will have to be considered. We can say that it is the area of planting by kind of crop and yield per unit area of the crop, for the result o multiplication of one of these two by the other will represent the farm income. Thus, the crop income of the farm is determined by the area of planting by kind of crop and yield per unit area of the crop under a given economic and technical condition.

A question will arise, then, about what regulates these two factors, because what regulates these two will be said to regulates finally the crop growing, consequently, the rotation.

In the following discussions, only upland field crops will be dealt with, while every of the farms investigated is a rice growing farmer and the rice is the most important product on the farm, and consequently, the upland field crops will be forced to be under the influence of the characters of the rice. Japan's agriculture can not be considered without rice, and it can be said that analysis of the factors regulating the rice cultivation is more important. The rice is, however, as is often mentioned, absolutely adapted to the geographical conditions of Japan and can be grown on the same field in successive years. Furthermore, rotation involves only upland field

crops, but not rice. Therefore, this article will deal only with upland field crops in order to make clear the course of logic.

III. Social-ecomic attributes of crop

Under given social-economic and technical conditions, the crop income (cash and products for farm-consumption) of the farm is determined by the kind of crop planted and area of land planted, provided the yield per unit area is fixed.

A question arises, then, about by what the kind of crop and the area of planting of each crop on the farm are determined.

The kind of crop planted and the area of land planted with each crop on the farms investigated are shown in Table 4. (the crops planted on the land of 10 *bu* or more).

Table 4. Planting area on 3 farms.

Farm / Area / Crops	A				B				C			
	1949 *se. bu*	%	1948 *se. bu*	%	1949 *se. bu*	%	1948 *se. bu*	%	1949 *se. bu*	%	1948 *se. bu*	%
Soy-bean	68.00	37.2	75.10	40.4	38.20	41.6	38.13	41.4	14.15	34.8	14.00	33.3
Barley	34.19	19.1	29.15	15.8	8.15	9.1	12.06	13.1	1.00	2.4	1.00	2.4
Wheat	40.13	22.3	53.19	28.6	18.05	19.5	14.14	15.6	10.00	24.0	9.00	21.4
Naked barley					13.23	14.8	13.23	14.8	4.00	9.6	5.00	11.9
Potato	6.00	3.3	5.00	2.7	5.00	5.4	5.00	5.4	4.00	9.6	4.00	9.5
Tabacco	10.14	5.8	8.14	4.5								
Rape									0.20	1.6	1.00	2.4
Cabbage									1.00	2.4	1.00	2.4
Onion	1.15	0.8										
Chinese cabbage	1.00	0.6	1.00	0.5	2.00	2.1	2.00	2.1	3.00	7.2	3.15	8.3
Spring radish					0.15	0.5	0.13	0.5				
Radish	2.15	1.4	2.02	1.1	3.00	3.2	3.00	3.2	1.00	2.4	1.15	3.6
Egg-plant	0.15	0.3	0.20	0.4	1.23	1.9	2.00	2.1	0.15	1.2		
Tomato	1.00	0.6	1.00	0.5	1.02	1.1	1.00	1.1				
Red-bean	10.00	5.5	5.15	2.9					1.00	2.4		
Cucumber					0.10	0.5	0.10	0.3			1.00	2.4
Sesame									1.00	2.4	1.00	2.4
Grape	4.00	2.2	4.00	2.1								
Soy-bean(green)					0.10	0.5	0.12	0.4				
Water melon	1.00	0.6	1.00	0.5								
Total	181.01	100.0	187.05	100.0	93.01	100.0	93.01	100.0	41.20	100.0	42.00	100.0

The table shows that there are some variations among these farms in the crops chosen for planting and also in the area of land planted with each crop and its percentage.

In 1949, the kinds of crops grown were thirteen in number for each of Farms A, B, and C, but the kinds were not same. In comparison to 1948, the kinds of crops for these three farms are different, but for Farm B.

As for the area of planting, there are differences not only in the area of planting for the same kind of crop, but also in its percentage to the total area of planting. The same is true in the comparison with 1948 too. Shortly, this means that the kinds

of crops and their area of planting vary with the farm and the year. If the difference in locality of each farm is widened and that in year is enlarged, the above tendency will present itself in a more magnified manner.

This gives rise to a question what are the factors which limit the kinds of crops and area of planting. That is the same in the case with the factors which affect the variation with individual farm, locality, and year.)

1. Profitability of Crop

It is quite natural for a farmer to seek cash income from sale of crops, as far as he leads his economic life in the society of commercial production, and it is, consequently, quite natural, too, that he chooses such crops to grow as are profitable from the viewpoint of economy and expands the area of planting of such crops. (Length of period of planting will be expressed in terms of area of planting.) Then, what sort of crop is profitable ? It can be said to be such one as brings larger net return per unit area of planting, if area of land is limited. It is natural for a farmer to choose those crops which can bring him large amount of net return and to plant them on as large area of land as possible.

To know about whether or not the farmer is actually doing planting on such rational basis as mentioned above, information on the actual situation on the farms investigated is given in Table 5.

It is sure in this case that the net income is the true measure. However, because it was difficult to calculate net income for each farm, each crop, and each field, the gross income per *tan* will here tentatively substitute for the net income. (The ma naging expenditure for each farm will have to be left out of consideration just here.)

Table 5 is a trial to examine the order of crops on each field which bring higher income, and to know whether such order will coincide with the actual order of planting area or not. This trial is based on the assumption that, as far as the planting on the farm is under the economic rationality, the two kinds of orders mentioned above must come into one.

Chief facts which we can see in Table 5 are as follows : The order in incomes does not necessarily coincide with that in area of planting. Despite the tendency logically expected toward emphasis centralized on the most profitable crop, *i. e.*, the tendency toward single crop farming, the actual situation fails to indicate a definite tendency, or on the contrary, the distribution of area of planting among different kinds of crops can be said to be rather scattered.

In Farm A, the incomes from different kinds of crops ranked as follows : tomato, egg-plant, tobacco, and onion, while the area of planting : soy-bean, wheat, barley, tabacco, and red-bean. On Farm B, the order in income was cucumber, chinese cabbage, potato, and tomato, but that of area of planting was soy-bean, wheat, naked barley, barley and potato. On Farm C, the income ranked in the following order : chinese cabbage, cabbage, wheat, naked barley, and wheat, but the area of planting : soy-bean, wheat, potato, naked barley, chinese cabbage.

Table 5. Order of gross income and planting area classified by crop.

Order	A farm				B farm				C farm			
	Gross income per *tan*		Area of planting		Gross income per *tan*		Area of planting		Gross income per *tan*		Area of planting	
	crop	sum *yen*	crop	%	crop	sum *yen*	crop	%	crop	sum *yen*	crop	%
1	tomato	24.000	soy-bean	37.2	cucum-ber	45.000	soy-bean	41.6	chinese cabbage	31.020	soy-bean	34.8
2	egg-plant	18.000	wheat	22.3	chinese cabbage	18.000	wheat	18.05	cabbage	27.000	wheat	24.0
3	tobacco	17.460	barley	19.1	potato	18.000	naked barley	14.8	wheat	13.500	potato	9.6
4	onion	16.500	tobacco	5.8	tomato	16.000	barley	9.1	naked barley	13.500	naked barley	9.6
5	water melon	12.000	red-bean	5.5	radish	12.450	potato	5.4	wheat	9.000	chinese cabbage	7.2
6	grape	10.000	potato	3.3	wheat	6.204	radish	3.2	red-bean	6.000	cabbage	2.4
7	wheat	9.024	grape	2.2	egg-plant	6.000	chinese cabbage	2.1	radish	6.000	barley	2.4
8	wheat	8.930	radish	1.4	naked barley	5.952	egg-plant	1.9	egg-plant	4.000	radish	2.4
9	potato	8.800	onion	0.8	soy-bean	2.604	tomato	1.1			red-bean	2.4
10	wheat	8.789	chinese cabbage	0.6			cucum-ber	0.5			sesame & *egoma*	2.4
11	radish	7.800	tomato	0.6			soy-bean (green)	0.5			rape	1.6
12	red-bean	7.200	water melon	0.6			spring radish & other	0.5			egg-plant	1.2
13	barley	6.000	egg-plant	0.3								
14	"	5.750										
15	radish	4.550										
16	soy-bean	4.200										
17	"	3.360										
18	"	2.100										

Note : $ 1=¥ 360

Attention must be given to the facts that there is hardly seen tendency toward single crop farming, and that there are differences between the two kinds of orders mentioned above. But in this case, it will have to be remembered that there is a question with regard to propriety in choosing the farms to be investigated (though the farms like these three are considered to take the overwhelming majority of all the farms in actual situation of Japan) as well as an imperfection with regard to substitution of gross income per *tan*, and that only in one year, for the net income as the measure of profitability.

As far as the farmer carries out commercial farming, it is quite a natural thing that emphasis should be centralized in choosing crops to grow on the most profitable crop. (In this sense, it can be said that choice is centered on the rice in Japan's agriculture, though it may be difficult to be called an ordinary commercial crop.

But in this relation, too, farm-consumption of rice must be taken into account).

What prevents the tendency toward single crop farming is essentially the technical conditions as mentioned already. However, although the order of income per *tan* does not necessarily coincide with that of area of planting, it still must be rocognized as a tendency that the planting is being done according to profitability of each crop. In fact, this can be seen in Table 5, though such tendency is not expressed in normal form in the case of these farms investigated. Therefore, it would be a matter of course that we must name the economic profitability of the crop as a factor which determines the kind of crop and area of planting. The amount of cash income from crops and their percentages to the totals, which concretely show economic characters of the crops, will be found in Table 2.

2. Self-sufficiency of Crop

It was already mentioned that the farmer chooses crops to plant according to economic profitability of the crop as far as he carries on commercial farming. Actually, however, most of Japan's farmers do not sell all the farm products. In this relation, it is not too much to say that we can hardly find a perfect commercial crop, as shown above in Table 3.

This means that there exists another factor regulating the kind of crop and area of planting, independent from economic principles. This factor is self-sufficiency of the crop,and it can be said that the self-sufficiency crop will be planted,irrespective of economic profitability of the crop, as far as the use value of the crop is sought.

On most of Japan's farms, we can find many perfect self-sufficiency crops, if not any perfect commercial crops. And most of the crops are the ones of double character, bearing both characters at the same time.

The crop of delivery (though tobacco has no self-sufficiency) is under controls of planting and price, and, being anything but a perfect commercial crop, is not necessarily planted in accordance with the economic rationality. From this point

Table 6. Kinds and planting area of crop classified by use.

Farm	Area & kind	Crop of delivery	Crop of self-sufficiency	Crop of self-sufficiency and sale	Crop of self-sufficiency delivery and sale	Crop of self-sufficiency and delivery	Total
A	area	*se. bu*10.14	1.00	20.15	108.13	40.19	181.01
	%	5.8	0.6	11.3	59.8	22.5	100.0
	kind	1	1	7	2	2	13
	%	7.7	7.7	53.8	15.4	15.4	100.0
B	area	*se. bu*	8.03	75.18		9.10	93.01
	%		10.0	8.7		21.3	100.00
	kind		5	4		4	13
	%		38.4	30.8		30.8	100.0
C	area	*se. bu*	17.05	10.15		14.00	41.20
	%		41.2	25.2		33.6	100.0
	kind		5	6		2	13
	%		38.4	46.1		15.5	100.0

of view, it is rather similar to a self-sufficiency crop.

I prepared Table 6 by classifying the crops into commercial crops, crops of delivery and self-sufficiency crops, and by computing area of planting and kinds of crops on the farms investigated.

On Farm A, of a total of thirteen kinds of crops (those planted on the land of ten *bu* or more), the "self-sufficiency and commercial" crops are the greatest in number, followed by the "self-sufficiency, commercial and delivery" crops and "self-sufficiency and delivery" crops in the order mentioned. In the area of planting, the "self-sufficiency, delivery and commercial" crops overwhelmingly occupy the largest portion with the "self-sufficiency and delivery" crops coming second and the "self-sufficiency and commercial" crops coming third. On Farm B, of the thirteen kinds of crops, the "self-sufficiency" crops are largest in number, with the "self-sufficiency and commercial" crops and "self-sufficiency and delivery" crops coming second. The "self-sufficiency and delivery" crops occupy more than 80 per cent of the total area planted, and the "self-sufficiency" crops and "self-suffiiciency and commercial" crops come in the order mentioned. On Farm C, of a total of thirteen crops, the 'largest number is included in "self-sufficiency and commercial" crops, the second largest number in the "self-sufficiency" crops and the least in the "self-sufficiency and delivery" crops. The largest area is planted with the "self-sufficiency" crops, the second largest with the "self-suffieiency and delivery" crops, and the smallest with "self-sufficiency and commercial" crops.

As described above, quite a number of crops which are grown not always in accordance with the economic rationality are found on farm. Also, inclusion of self-sufficiency crops will necessarily result in a larger number of crops planted on a farm, and obviously prevents the tendency toward single crop farming as a direction of logical and natural development of rotation. There are many questions with regard to why so many self-sufficiency crops are still grown on the farms of Japan. But they will not be mentioned here. The self-sufficiency crop is originally a crop corresponding to the feudal self-sufficient economy, and, therefore, being not always under economic rationality, is of the nature quite different from that of the commercial crop. Further studies will be needed before we can conclude that the self-sufficiency crops in Japan are of nature different from that of commercial crops. But, even assuming that the self-sufficiency crops connect with the principle of value production like the commercial crops, it is doubtful that such nature is realized substantially. Therefore, it would be safe to say that the self-sufficiency crops hold some element which not only retard reasonable development of the rotation but also prevents existence of the rotation itself. At any rate, it is obvious that self-sufficiency of the crop will produce such effects as to modify the kind of crop and area of planting adapted to commercial farming. Consequently, it is also clear that the self-sufficiency of the crop determines actually the kind of crop and area of planting.

The crops of delivery will be largely for sale, but are under controls of planting and marketing. Therefore, they can not be free commercial crops. Though they are not of so different nature from commercial crops as the self-sufficiency crops, the delivery system obviously modifies the economic rationality of the crop, and, therefore, it can be said, regulates the planting.

As mentioned above, the factors which determine the kind of crop and area of planting are the profitability and self-sufficiency of the crop and delivery system. They are social-economic factors, which represent the social-economic attributes of the crop. And this economy is the economy as a contradiction between economy and technique. Therefore, if economic conditions change, the kinds of crops and area of planting must change. The same is true when technical conditions change: This point will be discussed in the following.

IV. Natural attributes of crop

Under given social-economic and technical conditions, the crop income of the farm (cash and products for farm-consumption) is determined by the yield per unit area if the kind of crop and area of planting are fixed.

A question arises, then, about by what the yield per unit area (yield per *tan*) is determined.

The yield per *tan* varies not only with individual farm but also with individual field within a farm. This is shown in Table 7, which has been made up by calculating the yield per *tan* on each field of each farm investigated. This table indicates that the production of each crop by field of each farm varies even within a farm, and also that such variations are of a considerable size. This phenomenon is common among all the crops.

Now, it must be found out what the factors are which produce such differences in the productivity.

We can point out various factors which determine the yield per *tan* of the crop : that is to say that various factors contribute to determining the production.

In this relation, it is well known that certain combinations of crops (generally understood as rotation) can prevent reduction in production, and even increase production in some cases. And it is also a well-established fact that successive planting of the same crop on the same field leads to reduced yield, except for the cases of a few specific crops, and sometimes reduces it even to nothing. In most cases, combination of different crops is the only means to prevent decrease in yield.

We can not have it demonstrated in Table 7 what different effects on yield have been produced by different combinations of crops. The reason are that there exist still other factors than combination of crops which contribute to determining the yield, and that it is difficult to estimate the effects of combination of crops separately from other factors. To make a definite estimate, experimental research will be needed.

Table 7. Crop amount per *tan* in each field.

Crop \ Farm \ No. of field		1	2	3	4	5	6	7	8	9
Soy-bean (*to*)	A	7.5	15.0	12.0		12.0		10.5		
	B		9.0	8.7	9.0	9.0	9.0			
	C		12.5	10.0	5.0	15.0				
Barley (*to*)	A	23.0	23.0	24.0						
	B		33.0							
	C			30.0						
Wheat (*to*)	A					19.2		18.7		19.0
	B				13.2	13.2	3.2			
	C	15.0			10.0					
Naked barley (*to*)	A									
	B			18.6						
	C					20.0				
Potato (*kan*)	A		400							
	B	400	400							
	C		500							
Tobacco (*kg*)	A				194		194			
	B									
	C									
Cabbage (*kan*)	A									
	B									
	C		450							
Onion (*kan*)	A						330			
	B									
	C									
Chinese cabbage (*kan*)	A									300
	B	600	600							
	C	660								
Radish (*kan*)	A						600			350
	B	830	830							
	C	600								
Egg-plant (*kan*)	A						600			
	B							200		
	C			200						
Tomato (*kan*)	A						600			
	B							400		
	C									
Red-bean (*to*)	A							80		
	B									
	C			100						
Cucumber (*kan*)	A							150		
	B									
	C									
Egoma (*to*)	A									
	B									
	C			140						

Sesame (*sho*)	A B C			60						
Rape (*to*)	A B C			120						
Water melon (*kan*)	A B C						300			
Grape (*kan*)	A B C								200	
Soy-bean (green) (*kan*)	A B C							300		

It is still doubtless, however, that combination of crops plays an important part as a factor to determine the yield per *tan*[4].

If conbination of crops prevents decrease in yield resulting from successive planting of same crops, the reason why the latter brings about decrease in yield must be made clear.

This point, however, which has been a pending question since De Candle (1832), has not yet been made clear, especially with regard to the sick-soil[5], in the present stage of scientific and technical development.

But it is obvious that lowering of soil fertility is resulted in by seccessive planting. It can be remedied by manuring. In fact, the results of many experiments demonstrate that the rotation and manuring can not be considered separately[6]. And it can be said that this is the reason why emphasis is placed on legumes in determing combination of crops in rotation. At any rate, in the present stage of scientific and technical development where the reasons for reduced yield resulting from successive planting have not yet been made perfectly clear, the question left to us to consider (if the kinds of crops and area of planting are already given under the social-economic conditions) is naturally how to combine these crops, that is to say, the only way we can take is to find reasonable combinations of crops. In this view, it can be said that discovery of rotation was quite a course of nature.

Thus, it is obvious that the principal question of the combination of crops lies in determination of the yield. What kinds of crops should be put in a combination, then? It depends upon the characteristics of the crops to be combined. However, the science of the present level has not clarified adequately the characteristics of each crop, and, consequently, in the present stage of technical development, as is the case with successive planting in this regard, decision of crpos to be combined will have to rely upon experimental or experiential facts alone. This results in the fact, which is obviously seen, that the combinations of crops in rotation can only be shown as numberless examples in all countries, regions, and farms.

To conclude, it is apparent that combination of crops is a factor that determines the yiled per unit area of the crop, and, therefore, is a technical factor. It will be also obvious that such combination of crops can be said to originate from the natural attributes of the crop itself, though scientific findings are not sufficient with regard to the characteristics of the crop. And, if the kinds of crops and area of planting are to be understood as economy, the combination of crops will be understood as technique. The reason why the combination of crops affects the production has not been mentioned just here.

V. Conclusion

I have already stated that the rotation on the farm does not present a mere combination of crops, but also is an expression of social economic and natural attributes of the crops, which can be understood in unification of contradiction of economy and technique. If the rotation is a problem of mere combination of crops, only such a combination as can bring maximum yield will be chosen as a matter of course. However, in the actual practice of selecting crops for combination, the kind of crop and area of planting are already given by social-economic conditions. Therefore, the combination of crops can not be determined only by the technical conditions from the standpoint of the yield. Furthermore, it will have to be recognized that these two kinds of conditions are constantly changing actually.

In most of the discussions made so far on the subject of rotation, the scope of the discussion has been limited to the combination of crops. This must be said to be nothing but to take up phenomenal facts alone and to discuss only technical conditions. But if the kind of corp and area of planting are given before the combination of crops becomes the subject for consideration, we must say that social-economic conditions go ahead of technical conditions. Of course, the social-economic conditions do not go ahead in all instances. Even if so, however, there can not exist in a farm management any combination of crops perfectly out of influecne of the social-economic conditions. Shortly, the rotation system is realized under interaction of the social-economic attributes–(economy) and natural attributes–(technique) of the crop, and unification of such contradiction.

Now, how does the rotation present itself in actual circumstances of the farms investigated? It will be seen in Table 1 as follows:

Generally speaking, it is indicated in the table that the series of combinations of crops on all of Farms A, B, and C are decided in chief consideration of the individual field. Informations on Fields 1, 3 and 7 on Farm A, Fields 1 and 2 on Farm B, and Fields 1 and 5 on Farm C will demonstrate this point. However, as for Fields 4 and 6 of Farm A and Fields 1, 2, and 3 of Farm C, the combinations of crops have not been decided in chief consideration of the fields, but of the crops involved. If the economic rationality for commercial production regulates the planting of crops and realizes itself in it, the combination of crops is considered to

have to be decided in principal consideration of the crops. But in the actual examples, combination of crops decided in chief consideration of the fields appears dominant, and, to conclude, it is under unification of the two different kinds of considerations relative to combination of crops.

Such discord between the combination decided in chief consideration of the fields and that decided in chief consideration of the crops must be attributed to the fact that all the crops are of the nature of self-sufficiency crops or crops of delivery rather than of commercial crops. Another reason is considered to lie in the fact that there exist considerable differences among the fields in area, soil fertility, and other conditions.

The examples of the Norfolk rotation system or those seen in the agriculture of a part of Hokkaido are made up in chief consideration of the crops. The rotation there is possible to be observed on the scale of the farm as a whole, instead of on the scale of individual field, from the standpoint of the crops. This is because the economic rationality for commercial production is realized perfectly in the crops, and also because there is little difference among the fields in their conditions.

As stated above, the rotation can be understood under the unification of the contradiction between the kind of crop and area of planting, which originate from the social-economic attributes of the crop, and combination of crops, which originates from the natural attributes of the crop and determines the yield per unit area namely, it should be understood under interaction of economy and technique and unification of the contradiction between them. Therefore, the rotation is not merely the combination of crops. The combination of crops is a phenomenon and shows only a form.

We must say that discussion limited to combination of crops is far from true understanding of the essential of the rotation. As long as the discussion is limited to combination of crops, it can deal only with the yield per unit area, *i.e.*, technique. Consequently, it will never come to touch the problem of farm management in actual conditions.

I already pointed out that the rotation has necessity by nature to go in the direction of single crop farming, that is, it must move toward freedom of planting. The reason why such course is not followed in actual conditions lies in the technical conditions which work as limiting factors. Also, in the social-economic conditions under which the farms of Japan are placed at the present time, the self-sufficiency of the crop and the delivery system should be taken into account. This means that the crops are not always under economic rationality. In this view, though there is a cyclical combination of crops in actual practice on the farm, it is questionable, we must say, whether such combination of crops makes the rotation system in its true meaning or not.

To conclude, as far as the rotation is understood in unification of contradiction between economy and technique, any change in social-economic conditions or any

progress in technical conditions, which means a change in the essential of the rotation, will cause the combination of crops as a phenomenon to change as a matter of nature.

Thus, the rotation should not be understood as a fixed system, but as a developing and changeable.

Summary

It is said that the rotation of crop is one of the most important subject in the farm management. Two different courses must be considered in order to study this problem. One is the course of natural science, *i. e.* crop science, soil science etc., and the other is of social science.

When we take up the rotation as a problem in the farms it must be observed from the standpoint of the farm management. That is, the crops of farm possess two different charactors, social-economic and natual attributes. These different charactors do no always stand by each other, so that the rotation must be considered as a contradiction between *economy* (social science) and *technic* (natural science).

The actual examples of three farms in Miyagi Prefecture, which we observed in 1950, demonstrate the above mentioned points and could be summarized as follows :

The actual conditions of the rotation of each farm are shown in the Table 1. The reason why they prefer this system should be found in their incomes by the rotation, *i. e.* cash income (Table 2) and crop income (Table 3).

Now we can see the farm income in the results of multiplication of the planting area classified by crop kinds and the amount of products per unit area. Then it becomes necessary for us to consider what are the essential factors which regulate these two elements.

1. The factors which regulate the planting area classified by crop kinds (Table 4)
   (i) Economic profitability of crop ; it is shown by the cash income per *tan* (Table 5).
   (ii) Self-sufficiency of crop (Table 6)
   These are the social-economic factors.
2. The factors which regulate the amount of products per unit area
   The yield per *tan* of the farm is shown in the Table 7. We can consider many factors which regulate the yield, but the combination of crops is the most essential one. This is a technical factor.

Judging from the above mentioned (A) and (B), we can conclude that the farm income is controled by the economic as well as technical conditions, and the rotation system is determined by these two elements, in other words, it can be regarded as a realization of these two.

If one of these elements changes, the type of rotation system has to change of itself.

The rotation must be, therefore, considered not as a fixed system, but as a

flexible.

Literatures Cited

(1) S. Yasuda, *Saibaigaku-hanron* (*Crop Science*), 1st Ed., Tokyo (1930) 309
(2) K, Kautsky, *Agrar Frage* (translated into Japanese by I. Sagisaka), 1st Ed., Tokyo (1932) 51
(3) K. Kautsky, ibid, 53
(4) W. W. Weir, *Soil Science*, 1st Ed., Chicago (1936) 498
(5) Y. Takishima, Science of Agriculture (in Japanese), 3 (1949) 48
(6) Hokkaido Univ., Special Report of Farm (No. 1), Fac. Agri. (in Japanese), Sapporo (1929)

A Study on the Extention of Double-Crop Farming Technique for Paddy Fields in Tohoku Region*

Shûtarô Teshima and Jirô Katô

(Received June 15th, 1948)

I. Introduction

The agriculture in Japan has always been characterized by the smallness of its scales, intensive use of labor and its self-sufficiency. These factors constitute formidable obstacles in the way of any new and improved techniques being introduced for better efficiency. It seems, therefore, imperative that the exact nature of these difficulties should be first made clear and them proper remedies thought out.

In 1943 (before the Farm Land Adjustment Law was proclaimed), the authors carried out a series of experiments at the Uchinoura Experimental Farms of the Institute for Agricultural Research, Tohoku University, for the purpose of removing technical difficulties from the raising of barley on the paddy fields as a second crop.

II. Importance of double-crop farming for rice fields in Tohoku Region

Japanese agriculture is marked by three prominent features: 1) that rice farming forms the pivot of the entire farm industry, the total rice field area representing roughly 56 percent of the entire arable area, and the area under rice roughly 43 percent of the entire area under cultivation, 2) that all farm units are operated on the smallest scales in the world, averaging a mere hectare per unit, 3) that hand labor is intensively employed for farming and the labor used to work 0.1 hectare of farmland become 58 man-days on an average.

The above may be said to represent an average segment of the Japanese agriculture, – a pattern developed under the natural climatic and social economic conditions peculiar to Japan. Certain regional variations, however, may be noticed according to different sectors of the country, where these environmental conditions vary. To take rice farming only, a comparative study of the labor

* The 57th report of the Institute for Agricultural Research, Tohoku University. (1951)

expended and the production per man-day labor will show that Tohoku Region is decidedly the most backward area in Japan.

As stated in the foregoing, that the agriculture in Tohoku Region is most backward, is mainly due to the unfavorable climatic and economic conditions. Tohoku, comprising 6 prefectures, is a narrow strip of land extending from north to south in the northern part of Honshû or main island. Due to the Oou mountain range that runs through the territory lengthwise dividing it into east and west, the area is sometimes subject to heavy cold weather even during summer season, causing serious damage to farm crops. The area is also handicapped by its low social economic condition, as it is testified by its general industrial production index, which is markedly lower than those of any other arable areas. So far as rice production is concerned, Tohoku stands rather high on the nation-wide list. But this does not mean that Tohoku is well suited for rice farming. The real reason is that rice farming and forestry are the only major industries the Tohoku farmers have to depend upon for livelihood. It may be said, however, this very backwardness holds behind it plenty of room for future development and improvement.

A knotty problem facing Tohoku is how to cope with the climatic handicap imposed on its agriculture. As matters in hand, it should be bettered that the rice field is left idle until the transplanting season in the following year. As a way to solve this problem, double-crop farming for paddy field is under study.

The problem of double-cropping in Tohoku involves, in addition to technical difficulties, another difficulty arising from labor distribution. Solution of the problem therefore would seem possible only so far as feasible under these three unfavorable conditions, climatic, economic and labor. The authors tried to study the problem from the labor angle.

III. Present double-cropping situation in Tohoku Region

Acreage of rice fields in Tohoku capable of double-cropping is as shown in Table 1. Since the figures given are as of 1931, the current figures (1943) must be considerably greater. Table 2 shows the acreage, as of 1942, under barley raised as a double crop.

As may be seen by the foregoing tables, Fukushima and Akita have made a remarkable progress and double-crop acreage in both cases are far exceeding the potential acreages of 1931. This must be due to some favorable conditions, either social, technical or climatic. In the case of Fukushima, favorable natural factors evidently outweighed technical difficulties. In the case of Akita, where paddy and dry fields are not well balanced, it seems that high demand for vegetables from industrial area helped to speed up the double-cropping program. With the exception of these two prefectures, progress toward double-cropping in the rest of Tohoku Region has been rather slow, for which the following four factors seem to be responsible.

Table 1. Acreage of rice-fields in 6 Tohoku prefectures fit for double-cropping, as of 1931. Unit : *chō* (=2.45 acres)

Prefecture			Aomori	Iwate	Miyagi	Akita	Yamagata	Fukushima	Total	Rest of Japan
Acreage	Single crop		71,492	59,249	73,704	112,791	97,227	99,088	513,553	—
	Double crop		25	2,844	21,733	158	3,281	7,277	35,319	—
Percentage	Single crop		99.96	95.41	77.22	99.85	96.73	96.05	93.56	49.39
	Double crop		0.04	4.59	22.78	0.15	3.27	3.95	6.44	50.61
	Kind of 2nd crop	Ordinary	100.00	14.10	17.37	76.45	26.95	17.64	19.21	65.22
		Green manure plant		85.90	82.63	23.55	73.05	82.36	80.79	34.78

Table 2. Acreage under barley as second crop in rice fields, as of 1942. Unit : *cho*

Prefecture	Aomori	Iwate	Miyagi	Akita	Yamagata	Fukushima	Total
Rice fields	70,776	64,214	102,947	107,836	98,911	105,815	550,501
Second crop area (barley)	—	181.1	291.1	305.3	52.4	3,035	3,865
Percentage	—	0.28	0.28	0.28	0.05	0.29	0.027

Table 3. A comparative table showing potential and actual double-crop acreages. Unit : *cho*

Prefecture	Aomori	Iwate	Miyagi	Akita	Yamagata	Fukushima	Total
Potential acreage 1931	25	401	3,775	121	884	1,283	6,784
Actual acreage 1942	—	181	291	305	52	3,035	3,865
Percentage	—	45.14	7.71	252.3	5.93	236.5	56.97

1. Natural factors :
   Climatic — air temperature, snowfalls
   Soil — terrain, wet or dry
   Water — irrigation facilities
2. Technical factors :
   Farm techniques, particularly, selection of suitable seeds, manuring method, etc.
3. Labor factors :
   Family labor and hired labor

Farm management, notably, dry field farming in relation to labor
Organization of labor, notably in relation to collective farming

4. Social and economic factors :
   Rice deliverly system
   Control of fertilizers
   Fluctuation of prices of farm products
   Tenant relations

Now let us see how foregoing factors act in the case of Tohoku.

(1) In Tohoku, where the weather is very much colder than the rest of Japan, rice farming itself is much affected under low temperature, to say nothing of barley, which has to stand the rigors of the winter. It is therefore a matter of first importance that an available variety of barley that can best stand low temperature be selected as soon as possible.

A good irrigation facility is another important factor for success of double-cropping. Without good irrigation, a rice field has often to be kept wet until late in the season and it causes sometimes a damage to barley crop.

(2) Potential double-crop acreage may be expanded through soil improvement work by means of laying culverts, etc. But here again comes up a baffling economic problem of how to meet the necessary cost, to the technical difficulty.

(3) Selection of the available varieties of rice and barley seeds to fit the general conditions of a farm in relation to their yields is another important factor that may decide the results of this double-crop farming.

(4) In a locality, where double-cropping is only partially operated, and where collective labor is used for rice planting and reaping, a double-crop farmer may find himself unable to devote his own family labor to his own work. Double-crop farming is not likely to thrive in such a locality, and it will be desirable for double-cropping farmer to control labor system adequately.

(5) Farm work involved in double-cropping usually has to be rushed in a short term of two or three days during the busiest season of the year for Japanese farmers. This presents another problem in these days of labor shortage.

(6) The fact that double-crop farm work coincides with the harvest season, when the farmer is generally worked to death, naturally causes in the mind of the farmer a feeling of dislike to the additional and unaccustomed labor entailed by double-cropping.

(7) The art of manuring the soil correctly for the rice-barley-rice rotation, which requires considerable skill and experience extending over several years, may be considered as another difficulty in the way of successful double-crop farming.

(8) Farm adjustment and top-soiling required for barley raising may add to the feeling of troublesomeness referred to under item (6).

(9) The clashing of rice thrashing work for early delivery with the seed-time of barley often causes the farmer to miss the right moment for sowing barley.

On the other hand, however, a growing tendency is noted to expand barley acreage as a result of tightening up of rice delivery system.

Shortage of cattle feed, ever since the war years, is stimulating the expansion of double-crop farming.

Here is a case, where double-cropping has been spurred by tenant-owner relations. In certain localities, other than in Tohoku, high tenancy fee imposed by the land owner drove the tenant to put more efforts into double-cropping. To cite a reverse example, a petty tenant farmer's desire to work double-cropping to eke out his scanty earnings accruing from rice farming was ruthlessly turned down by the landlord who was afraid double-cropping would deteriorate the soil.

We have listed above some factors blocking double-crop farming. Now let us consider what then are the farmers who are in a favored positions to carry out double-cropping. We will review the matter in detail, dividing the farmers into 3 classes : petty, medium and large.

1. Petty farmer

Petty farmer, whether tenant or land-owner, upland farmer or lowland one, is mostly part-time farmer. As such, he is generally but a poor possibility as a double-crop farmer.

2. Medium-scale farmer

(i) Farmers belonging to this category, particularly those living in the suburbs of a large city, generally turn their time and energy to horticulture rather than to general farming for higher profits. Consequently their possibilities for double-crop farming are exceedingly low.

(ii) Medium farmers living in upland farms area generally find it more profitable to concentrate on upland farming than on double-crop farming on rice-fields. Hence their possibilites are low ranking next to (i).

(iii) In the case of those working both upland and lowland fields, they generally devote their upland fields to vegetables and double-farm the lowland fields for barley for delivery. Their possibilities seem somewhat higher than (i) and (ii).

(iv) Medium farmers solely working rice-fields seem to have higher possibilities than any of the foregoing three categories. They usually reserve small bits upland farm in their possession for vegetable production and double-farm the paddy fields for production of ersatz food material and cattle feed. Hence higher possibilities.

3. Large-scale farmer

Large-scale land-owning farmers in paddy fields area usually have high double farming possibilities, ranking next to the medium-scale farmers at same area.

Having a large acreage of farm-lands and a large area under cultivation, they generally have plenty of labor at their disposal, because of their higher positions in the community as land-owners. Hence their possibilities are high.

The reverse is the case with big farmers in an upland area. Whether horticulturists or general farmers, their chances are rather slim because of insufficiency

of labor at command. More so in the case of tenant farmers or owner-tenant farmers.

In brief, of all categories, large-scale land-owning farmers and medium-scale farmers in a paddy field area seem to have the higher possibilitities as double-croppers.

IV. Rice-barley double-farming, as operated in Uchinoura Experimental Farms of Institute for Agricultural Research, Tohoku University

Experimental operation of barley farming as a double crop following the reaping of rice has been under way since 1941 at Uchinoura Experimental Farms under close co-operation with Institute for Agricultural Research. The experiments so far made have disclosed a number of problems involved, which will be reviewed below item by item.

1. Natural factors disqualifying rice-fields and difficulties of farmers for double-cropping

Total acreage of rice-fields in Uchinoura fit for double-cropping is roughly 28 *cho* (*cho*=2.45 acres). Deducting therefrom fields owned by outsiders, the figure reduces itself to 15 *cho* (45% off), which represents 18.2 percent of the total area of rice-fields (82.8 *cho*) owned by the entire Uchinoura Farmers Union members. After further reductions in the shape of fields reserved for seed-beds and those beyond easy reach of the farmsteads or remote from farm lanes, the final area fit for double-cropping dwindles into a mere 7.3 *cho*, representing 8.86 percent of the entire acreage under cultivation.

Another curbing factor is that double-cropping can not be repeated yearly on the same field, and that early and late varieties of rice must be rotated alternately.

In 1942 actual double-crop acreage at Uchinoura totaled 1.58 *cho*, and 1.26 *cho* in 1943. Such a niggardly figure reflects the farmers' general conditions as well as the scarcity of suitable lands at Uchinoura.

Number of full-time farmers owning potential double-crop fields in Uchinoura

Total number of full-time farmers	52
Number of potential double-crop field owners	24
Owners of potential fields along farm lanes	32
Owners of potential fields within 300 meters of farm house	14

Farmers possessing available fields to operate, and those not operating double-cropping

Farmers owning fields fit for double-cropping	7
Farmers operating double-cropping without fit fields	2
Farmers owning fit fields, but not working double-cropping	14

An investigation made in 1943 on the family circumstances of the 14 farmers not operating double-cropping disclosed that 4 of them were families whose male

members were drafted for military service, 3 were part-time farmer and high-wage-earners, while the remaining two were families of aged people. Aversion to the troublesome double-cropping techniques seems to be another disqualifying factor.

Farmers working double-cropping are generally keepers of work animals and own upward of 1.8 *cho* farmlands, – for the most part operating 4 to 5 *cho*.

In those areas under the said circumstances, some farmers are found who are under necessity of operating the double-cropping with no fit field of their own. To them, however, most other farmers would not lease their paddy-fields to let them meet their needs because of the fear that it might decrease their own rice yields there.

In short, observation reveals nearly 90 percent of restriction is caused to double-cropping on those paddy-fields by natural conditions and, moreover, when viewed from the standpoint of farm management, some 30 percent of restriction is incurred from unfavorable distribution of fit field for double-cropping among farmers.

2. Technical difficulties involved in cultivation

(i) Questions concerning the variety of rice and barley for double-cropping

The varieties of rice in this area is mostly middle-late variety with 7 percent of early rice mixed in it. Late rice transplanting caused by the irrigational conditions and also the quality of soil have something to do with the use of the said varieties of rice. It is favorable for rice transplanting after crop of barley, while sowing of barley faces sometimes inconvenience after cropping of rice from paddies.

(ii) Questions on barley sowing and rice cropping season

According to the investigation conducted in 1942, 90 percent of rice harvesting was made about 15 October and sowing of barley was started generally from 5 through 15 October. The most appropriate season for barley sowing being as above mentioned, the said sowing here is a little late. And a door-to-door investigation disclosed the fact that every farmer puts his hand to barley sowing work after but not before or during the rice harvest season regardless the advent of the proper season for barley sowing. In other word, no farmers start barley sowing until they have completely finished the rice harvest, most important work of farm management in fall. It tells the fact that they have no interest of operating the double-cropping in terms of different ripening periods of different kinds of rice. To correct this tendency, planning of all management is badly needed. For instance, they should know that cultivation of only late rice by the mere reason of its large yield become too late for sowing of barley, and so they ought to consider the combination of early-middle or early or latest rice planting. Furthermore, along with the selection of kinds of rice, calculation of needed number of days from the start through the end of rice cropping in respective areas, taking the amount of family labor into consideration are required, at least, to avoid the delay of barley sowing.

(iii) Questions on barley crop season and rice transplantation season

Even the earliest barley "Kinaizatsu" will ripe after 75 percent of rice transplanting is over. As a matter of fact, water is led into paddies a week before the transplanting and it means the removal of barley. That is, the broader the margin between the barley ripening season and rice transplanting season, the less yield of barley will follow.

But on the other hand, in case where the margin is small, then, there is a tendency that the rice transplanting is postponed beyond the most suitable period for it and that causes the decrease of rice crop.

3. Fact-finding investigation of farmers under double-cropping at Uchinoura village

The authors have so far given the outline of the question relative to double-crop farming in the bloc as a whole. Further, the four representative farmers who are operating the double-cropping are investigated to find out their actual conditions.

The record with regard to cultivation covers the data from the barley sowing season in fall, 1942 through the barley threshing season in June, July, 1943, and as to family labor the data from January, 1943 till December of the same year were given. Explanation shall be given in order.

Table 4. Farm size and labor power of selected farmers.
Unit : *tan* (=0.1 *cho*=0.245 acres)

Number of farmers	Paddy fields	Acreage fit for double-cropping			Actual double-crop acreage	Field				Labor power (interms of ability)	Area per a labor power
		Elevated field	Field along farm lanes	Within 300 meters reach from house		Ordinary field	Vegetable field	Fruit-tree field	Total		
5 of III	19.7	8.0	6.0	6.0	1.0(1942) 2.0(1943)	0.2	1.0	2.3	3.5	2.2	10.5
10 of III	27.0	10.0	9.0	3.0	1.0(1942, 1943)	3.0	4.5	1.0	8.5	4.6	7.7
1 of IV	30.0	2.0	2.0	—	0.8(〃)	2.2	2.0	—	4.2	3.4	10.3
2 of IV	16.7	2.0	2.0	2.0	1.0(〃)	1.4	1.8	—	3.2	2.4	8.4

(i) Farm size and labor power of selected farmers (Table 4)

(ii) Outline of cultivation and needed labor

(a) Combination of varieties of rice and barley and periods for sowing, transplanting and harvesting (Table 5)

(b) Yields of barley and rice in double-cropping (Table 6, 7) As shown in the above Tables, yield of barley in double-cropping can not be said in any way excellent except at the farmer III 5 which secured 2.8 *koku* in 1941 and 3 *koku* in 1942. In the case of this farmer III 5, soil condition was more favored and cultivation was conducted in a more intensive system than in

other farmers. And also the yield of rice was greater than average.

Generally speaking, yields of rice in double-cropping do not differ so much as in case of barley, and a little care and improvement in technics will secure the average yields.

Table 5. Combination of varieties of rice and barley and periods for sowing, transplanting and harvesting.

Farmer III/5	1941	1942	1943
First crop rice	Nôrin No. 1 X/1 Cropping	Tsuruuruchi X/8 Cropping	Hinomaru IX/25-29 Zennoo Cropping
Barley	Kinaizatsu X 8 Sowing VI/16 Cropping	Kinaizatsu X 8 Sowing VI/10 Cropping	Kinaizatsu X/22 Sowing
Second crop rice	Ginbôzu VI/20 Trans-planting	Ginbôzu VI/16 Trans-planting	Not yet determined
Farmer III/10			
First crop rice		Nôrin No. 1 X/3 Cropping	Zennoo X/18 Cropping
Barley		Kinaizatsu X/20 Sowing IV/11 Cropping	Kinaizatsu X/26 Sowing
Second crop rice		Ginbôzu VI/12 Trans-planting	Not yet determined
Farmer IV/1			
First crop rice		Fukubôzu X/17 Cropping	Tsuruuruchi X/18 Cropping
Barley		Kinaizatsu X/20 Sowing VI/14 Cropping	Kinaizatsu X/24 Sowing
Second crop rice		Tsuruuruchi VI/19 Trans-planting X/10 Cropping	Slated to use Tsuruuruchi
Farmer IV/2			
First crop rice		Nôrin No.1 X/10 Cropping	Hinomaru X/18 Cropping
Barley		Kinaizatsu X/20 Sowing VI/18 Cropping	Kinaizatsu X/30 Sowing
Second crop rice		Hinomaru VI/20 Trans-planting X/10 Cropping	Not yet determined

Table 6. Yield of barley in double-cropping.
Unit : *tan* (=0.1 *cho*=0.245 acres), *koku* (=about 5 bushels)

Years	Farmers	Yield of barley (per *tan*)
1941	III/5	2.8 *koku*
	III/10	2.0
	IV/1	0.9
	IV/2	1.0
1942	III/5	3.0
	III/10	2.1
	IV/1	1.6
	IV/5	1.2

(c) Competition of labor distribution among barley and rice farming (Table 8)

α. Rice transplanting season forp addy fields At the case of the farmer III/5, the rice transplanting in 1943 was conducted during 20 days from June 1 to 20 and barley was harvested on June 10.

Table 7. Yield of rice after cropping of barley.
Unit : *kan* (=3.75 kg.) *koku* (=about 5 bushers)

Years	Farmers	Varieties of rice	Rice straw	Uncleaned rice
1942	Common	Nôrin No. 16 (Average 2 points)	118.9 *kan*	2.340 *koku*
	〃	Tôhoku No. 14 (Average 2 points)	93.1	1.777
	III/5	Ginbôzu	121.5	2.280
	III/9	Aikoku	150.0	2.430
	Average		128.1	2.259
1943	III/10	Ginbôzu	235.5	3.41
	III/7	〃	136.8	1.86
	III/5	〃	198.9	2.71
	Average		190.4	2.66

Table 8. Labor used for double-cropping on paddy field classified by farmers, months and types of work.

Kinds of work / Month	Rice cultivation		Vegetable cultivation		Miscellaneous work		Other miscellaneous work		Total (excluding the double-cropping)	Hired			
	Family labor	Hired labor	F. l.	H. l.	F. l.	H. l.	F. l.	H. l.		Rice cultivation	Vegetable 〃	Miscellaneous	Others
Farmer III/5													
Jan.	24.9	1.0	3.6		9.3		64.7		103.5				
Feb.	10.6		8.9		12.1		46.4		98.0				
Mar.	6.6(2.0)		34.6		37.8		22.7		101.7				
Apr.	25.3(5.0)	1.0	23 2		15.9		27.8		94.2	8.0	2.5		
May	20.8		42 25		23.35		21.6		108.0		1.0	3.8	
June	77.95(3.0)	16.0	24.05		1.3		2.4		121.7	5.1	2.0		
July	39.2(7.0)		34.9		5.2		7.0		90.3	2.0			
Aug.	3.0		22.1		16.0		35.1		76.2				
Sep.	26.15	9.6	24.6		6.0		35.1		101.45		1.0	6.0	
Oct.	52.0(6.0)	5.5	19.95		4.0		11.5		92.95	2.8			
Nov.	37.9	0.8	19.85		2.25		15.0		75.8	2.5		0.8	
Dec.	28.5		18.25		7.5		40.9		95.15	1.0			
Famer III/10													
Jan.	46.6		1.6		9.7		56.5		114.4				
Feb.	22.5		3.5		12.0		65.0		103.0				
Mar.	11.0(3.8)		1.5		16.5		82.3		111.3				
Apr.	17.8(1,3)		19.5		12.3		69.4		119.0		7.5		
May	16.0		29.25		39.75		51.55		136.55	5.0		1.0	2.0
June	18.1(3.5)	24.5	16.7		4.5		9.05		72.85	17.85	2.5		
July	52.5(3.0)		33.15		6.55		26.2		118.4	16.0	2.9	1.0	0.8
Aug.	10.75		33.9		3.5		47.75		95.9		3.0		1
Sep.	16.5		25.05		18.5		44.5		104.55		2.5	1.0	
Oct.	66.25(6.0)	3.0	10.3		4.5		21.5		105.55	2.5	2.0		
Nov.	21.3		31.05		1.0		—		53.35	2.0	2.0		
Dec.	41.5		4.4		3.25		2.8		51.95	2.5			

Farmer IV/1											
Jan.	57.76		—	12.65		30.6	100.85				8.8
Feb.	49.5		4.4	12.0		27.8	93.7				
Mar.	28.1(1.7)		6.8	24.5		21.8	81.2			4.0	
Apr.	14.3		20.7	5.2		46.3	86.5	2.5			1.0
May	29.0		6.3	22.4	3	26.4	87.1	1.0			0.5
June	76.8(1.5)	17.5	10.4	4.6		6.3	115.6	2.9			
July	53.9(0.5)	8.5	27.0	4.6		8.4	102.3		0.5		
Aug.	2.3		18.2	4.0		68.4	92.9				
Sep.	27.3		11.9	3.0		57.8	100.0				
Oct.	60.0(6.0)	10.5	6.6	16.4		18.1	111.6	3.8		0.5	0.5
Nov.	83.0		2.6	9.0		13.4	108.0				
Dec.	67.4		9.4	3.0		28.4	108.2	2.5			
Farmer IV/2											
Jan.	14.24		0.4	4.0		24.0	42.64	2.2			
Feb.	12.6		—	6.94		30.8	50.34				
Mar.	23.6(0.3)		3.0	12.8		17.6	57.00				
Apr.	14.1(1.3)		28.4	1.7		15.6	59.80				
May	20.6		21.5	0.5		34.2	76.80	1.0	1.6		
June	28.4(3.0)	16.0	6.8	4.0		5.6	60.80	4.4			
July	30.9(2.4)	3.0	18.6	—		1.0	53.50	3.8			
Aug.	5.7		6.1	—		—	11.80				
Sep.	13.44		31.7	5.9		2.8	53.84				
Oct.	39.7(6.0)	6.0	6.5	5.3		22.2	89.70	6.8			
Nov.	22.7	3.0	8.4	1.0		—	35.10	2.6			
Dec.	33.1		4.5	3.0		6.3	46.90	2.0			

Note : Figures in ( ) indicate labor used for double-cropping.

By the III/10, the rice transplanting was held from June 3 to 14 and double-cropping barley was harvested on June 11, three days before the completion of rice transplanting. The reason was that the last rice transplanting was made on the field where the winter barley in double-crop farming had been harvested.

By the IV/1, the rice transplanting was started on May 31 and closed on June 19. Barley cropping was made 3 days before its completion. In the farmer IV/2, the transplanting was started on June 2 and closed on June 22, barley cropping being made four days before its completion.

Except the farmer III/5, the rice transplanting was conducted by every farmer finally on the field where double-cropping is carried on. Those farmers hired 1.5 or 1.6 farm laborers for rice transplanting. And every farmer, except the farmer III/10 whose family labor was plenty, took such a long period as of 20 days. Except the farmer III/10, they need three men's labor power for double-cropping and even the use of hired labor power can not save the two days delay adding to 20 days for transplanting. It is a question to be considered.

In short, ratio of labor power used for double-cropping was from 1.3 percent to 5 percent to total labor power in June and it means only 2 percent to 10 percent to labor power for rice cropping.

In this season, the most intensive work is required to complete the work at the shortest period, and consequently farmers are reluctant to set apart their labor for double-cropping even though it is a matter of a few days.

By the above mentioned data, it will be infered that a type of double-cropping which take less than twenty days and about 10 percent of labor (in June alone) is practicable for those farmers.

β. Rice cropping season Table 9 shows the relations between the date of rice cropping and the date of double-cropping barley sowing.

Table 9. Ricc cropping dates and double-cropping barley sowing dates.

Famers	Rice cropping period Start End	Needed days	Barley sowing dates	Days between rice cropping and barley sowing
III/5	9/25——10/19	24 days	10 22	3 days
III/10	9 25——10 23	28 〃	10 26	3 〃
IV/1	9/19——10/17	28 〃	10 24	7 〃
IV/2	9/21——10/16	25 〃	10/30	14 〃

As shown in Table 9, the barley sowing is generally conducted after the completion of rice cropping. And by the III/5 and III/10, it was made immediately after the rice cropping and yet it showed the delay of about two weeks. And by the III/1 and III/2, the barley sowing was given after a lapse of a considerable time from rice cropping. It is important to note, from point of view for guidance, the fact that farmers do not sow barley until the completion of rice cropping, though it is evident that the yield should be affected badly.

In this month every farmer hired laborers, and yet it was noticed that, judging from the needed number of days for rice cropping, the cropping was did not proceeded in proportion to farm size and total labor. As the time for cropping is different according to the kind of rice, the rate of progress can not be figured out merely in proportion to the farm size and labor.

So it is concluded that when a farmer wants to conduct double-cropping, it is required to consider the combination of variety so as to finish its rice cropping at a possible earliest period as an essential part of the farm management.

(d) Competition of labor distribution among double-cropping and vegetable cultivation within the scope of farm management Labor is more needed for vegetable cultivation in July than in June and October. The farmers III/5 and III/10, which show more labor distribution in June and October, were obliged to do so for their orchards. But, for other ordinary vegetable cultivation farmers try to save labor as can as possible in those two months. The rate of labor distribution in June, July and October respectively assorted is as follows :

In July, – threshing of barley in double-cropping, – in the vegetable field, barley cropping, carrot sowing and welsh onion transplanting, and onion's harvest, – in the orchard, care of fruit trees, spraying for insects control, and wrapping of fruit, – those are factors which call for labor distribution.

In the aforesaid factors, the orchard will take the largest part of labor. At this season, threshing of barley, weeding in rice paddies, care and harvest of vegetables, and wrapping of fruit on trees, – each of which is to need a share of appropriate amount of labor.

But, as a whole, labor needed in this month is less than in June. So it seems possible that the farmers make some plans to proceed their work smoothly, though each type of work has its proper period for its effectiveness.

It was noticed, too, every farmer was doing barley threshing after weeding rice paddies.

In June, vegetable cultivation is more directly affected by the rice transplanting on paddies rather than barley cultivation in double-cropping. That is, the rice transplanting period is restricted by plucking fruits, vegetable planting and splaying, and it also gives its influence on double-cropping work.

In October, there come barley sowing, vegetable sowing and fruit harvest at a time. But, as a matter of fact, different from the circumstances in June, friction in labor distribution is comparatively little in this month as the reuslt of efficient arrangement of varieties of rice, *viz*, early, middle or late one, and securing vegetable cultivation in the intervals of rice cropping and making double-cropping at paddies after rice cropping. And in this way they can avoid the direct conflict between vegetable cultivation and double-cropping, though the amount of labor is pretty big in this month. It is probably due to the conditions in this month that each type of work allows favorable combination each other.

Summary

If barley could be cultivated on paddies as double-cropping in Tohoku Region, it would make a very important start for increase of food product and for foundation of agricultural improvement in this area.

The subject of the present study is taken up from this point of view and the authors have studied chiefly concerning labor as a link of the agricultural extension study in 1943.

The authors analysed the difficulties hitherto perceived in barley cultivation at paddies and classified them under categories, *viz.*, 1. Natural conditions 2. Technical conditions 3. Labor conditions 4. Social and economical conditions, giving explanations to each item.

As this program has been tentatively conducted by farmers at Uchinoura Experimental Farms, the authors investigated their actual conditions and based upon the real findings they studied to locate the causes of difficulty for double-cropping.

The results of study are as follows :

1. The natural condition of those fields where barley in double-cropping is conducted. First essential is well drained land and second is convenience for

work, for instance, the field along the farm lane and that not far from cultivater's houses. But not every farmer is fortunate enough to have this kind of suitable field for double-cropping purpose. So from the standpoint of farm management, we must admit the restriction resulted from irregular distribution of field in the bloc.

And in connection with rice cultivated on paddies, barley must be sown only on the paddies where early rice was planted in previous year, and on the same field late varieties will be planted that year.

As the thing is conditioned in this way the restriction on possible size for double-cropping is of no simple question.

In figuring out the plans for double-cropping we should examine those points very carfully.

2. Investigation of individual farmers disclosed that each farmer begins barley cultivation only after the completion of rice cropping, no one sows barley during the time when rice cropping is conducted, even if the best season for its sowing is close at hand. This is probably psychologically so for farmers who put special emphasis on rice cropping in autumnal farm working.

3. Motive for double-cropping reflects, no doubt, the pressed circumstances of foodstuffs and feed shortage. Some farmers want to meet the required qouta of barley on the field by using paddies in terms of double-crop farming. This tendency is especially noticed among those who use fields as orchards.

4. Labor distribution to and among double-cropping, comparing with single rice cropping or vegetable cultivation was investigated in details by each farmer and each month, and the authors have arrived at the conclusion that for adjusted distribution of labor between barley and rice croppings in double-crop farming, rational management of vegetable cultivation on the field is prerequisite. This means the necessity of proper distribution of labor all the year round. The authors have confirmed the said fact through their investigation of those farmers.

Ecology of Mangoku-Ura Inlet with Special Reference to the Seed-Oyster Production*

Takeo Imai, Masayoshi Hatanaka, Ryuhei Sato and Seiichi Sakai.

(Received December 10, 1950)

I. Introduction

Mangoku-ura is an inlet situated in the north western corner of Oshika Peninsula, Miyagi Prefecture, connecting itself with Ishinomaki Bay in the south through a short narrow strait. It is about 1,800 acres in area, and shallow with an average depth of less than 2 meters. But the innermost part forms a deeper basin with maximum depth of 5 meters in the centre. Except the area around its mouth, over 80 per cent of the whole inlet is densely covered with vegetation of eel-grass, *Zostera marina* L. Through the thicket of eel-grass, four channels run inward from the mouth, two along both coasts and two through the middle part. Water goes in and out through the strait and these channels at ebb and flood. The tidal range averages a little over 1 meter. Bottom of the mouth part as well as that of the channels consists of gravel or sand, while that of the eel-grass bed is of muddy sand. Since no river pours in except a few small streams, the salinity of its water remains relatively high unless it is diluted with heavy rains. General shape of Mangoku-ura is shown in Fig. 1.

Several cultural and fishing industries are practised there. Among them seed-oyster production, cultures of edible oyster and laver are the most important. Fishing of sea-cucumber by hook, and of mullet, goby and minnow by trap, hook or line are also performed accessorily but the amount of their production is not significant. The distribution of main culture industries is shown in Fig. 2.

Annual production of seed-oysters in this Inlet is next in amount to that of Matsushima Bay. They, as well as adjacent waters, produce two million "*rens*"(1) of seeds, which cover 60 to 70 per cent of the total amount of oyster seeds used for culture in all Japan, and nearly 50,000 cases of seeds(2) exported to the Pacific coast of U. S. of America annually (Glud, J. B. and C. E. Lindsay, 1949).

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* The 58th report of the Institute for Agricultural Research, Tohoku University. (1951) Contribution from Onagawa Fisheries Laboratory.

(1) 5 feet wire by which 70 100 empty oyster shell are strung.

(2) One case contains 12,000 or more spats in case of unbroken mother shell and 18,000 or more in case of broken.

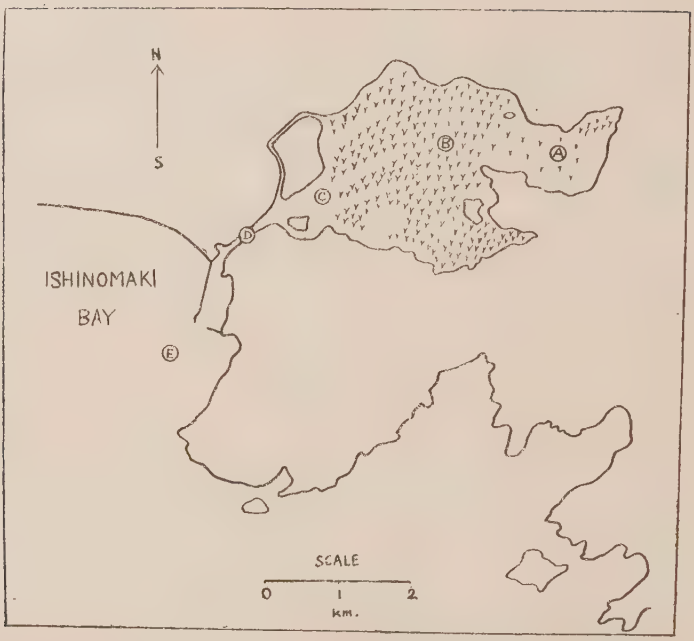


Fig. 1. Sketch-map of Mangoku-ura showing the distribution of eel-grass and stations of observation.

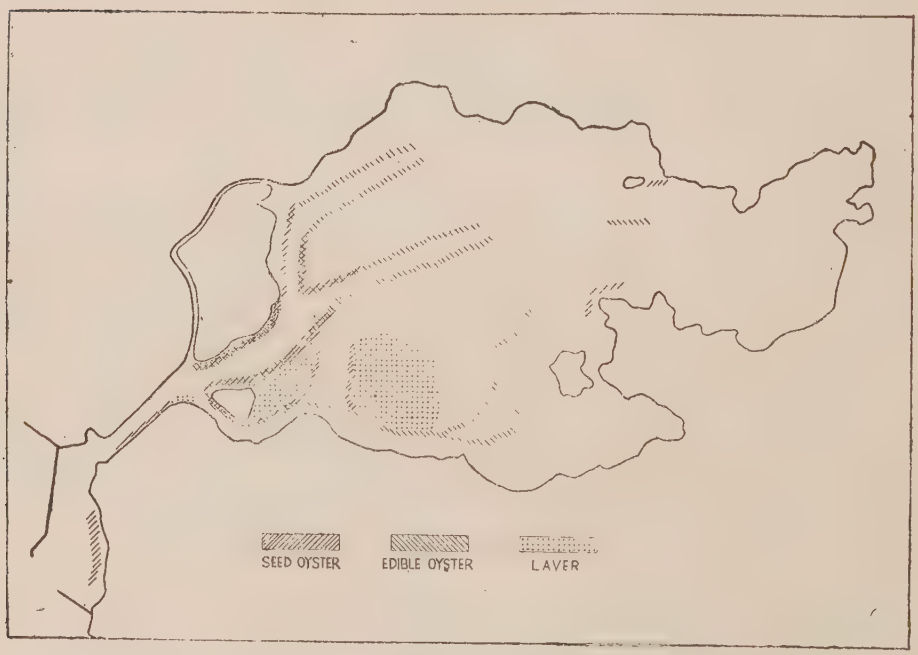


Fig. 2. Distribution of culture industries in Mangoku-ura.

We made a survey of the Inlet, because we considered it worth while to know the ecological conditions which enabled it to produce a great amount of oyster seeds. Characteristic of Mangoku-ura as well as of Matsushima Bay is that these shallow waters are densely covered with eel-grass, which would disintegrate and decompose during summers when natural spawning of oyster occures. In the laboratory, we have shown the evidence that the oyster larvae feed on a non-colored naked flagellate isolated from the Inlet, presumably identified as *Monas* sp. (Imai *et al.*, 1949). Moreover it has been proven that *Monas* propagates vigorously in a culture medium enriched with extract of eel-grass. With these evidences at hand, we wanted to grasp the relation between the life cycle of eel-grass and the production of seed-oyster.

Zostera marina has a wide distribution in the world and it often flourishes in bays and estuaries. It is well known that such vegetation offers not only favorable nursery grounds for fry of coastal fishes but also propagation ground for small crustaceans. It was reported that in the semiclosed area along Danish coast with dense vegetation of *Zostera*, the eel-grass was a main source of primary food and that the amount of its production was comparable to that of nearby coastal waters (Jensen, 1914 and Petersen, 1918).

The distribution, morphology and life history of eel-grass have been studied by many researchers, particularly from the phenological interest. Setchell (1929) made a thorough analysis on the phenology of *Zostera marina*. In Japan Miki (1933–1934) and Arasaki (1950) also made contributions in this field.

However, so far as we are aware, no analytical study has been reported as to the influence of vegetative cycle of eel-grass upon the chemical nature and accordingly upon the productivity of the water. In Mangoku-ura, Ishida (1935) reported the change of the degree of oxygen saturation and pH in the water caused by dense growth of eel-grass in sunlight. However no systematic survey has ever been conducted in connection with the ecological cycle of the Inlet.

In this study, we traced the seasonal changes of physical and chemical characters of the Inlet waters together with the vegetative cycle of the eel-grass. We also made an observation on the abundance of micro-plankton, particularly of non-colored naked flagellates. The survey, so far, was of preliminary nature. But we could arrive at a tentative conclusion as to the relation between the ecological elements and the production of oyster seed.

Before proceeding further, we express our thanks to the Fisheries Experiment Station at Watanoha for the aids given during the survey and to the Ministry of Education which defrayed a part of the expense.

II. Method

The observations stretched two years from April in 1942 to April in 1944, during which the hydrographic and biological surveys were carried once or twice a month.

Survey stations are indicated in Fig. 1. Station A was selected in the innermost region of the Inlet, where the water was kept from directly interchanging with the outside bay. It was a basin about 5 meters deep at most with somewhat thick growth of eel-grass. Station B was selected in the middle region of the Inlet where the eel-grass grew thicker than at Station A, with shallow water of 2 meters depth. Here the interchange of water with the outside bay is very meager. Station C was set in the channel near the mouth. The depth was 2.2 meters at mean tide level. Here the interchange of water was rather prominent at ebb and flood. Station D was a point in the central part of the strait with a depth of 3 meters. In Ishinomaki Bay, just outside the wharf, Station E was located at the point with 10 meters depth at mean tide level.

Water samplings at these stations were made from surface layer and bottom layer at 0.25 meters above the bottom. At Stations A and E, samplings were also made from the middle layer.

The salinity was determined by titration with silver nitrate. pH value was colorimetrically measured with thymol blue and cresol red as indicators. Dissolved oxygen was measured by the Winkler method and percentage oxygen saturation was calculated from Fox's tables. Among nutrient salts, inorganic phosphate and silicate were measured at every occasion during the whole period but nitrogen compounds such as nitrate, nitrite and ammonia were determined only in the latter half of the period. The determination of these nutrient salts were made by the well known methods described in Kaiyo-Kansoku-ho (Kaiyo-kishodai, 1940). In order to estimate the standing crop of phytoplankton, Harvey's method of acetone extract was employed (Harvey, H. W., 1934). 100 liters of water was passed through a net of bolting silk having a mesh of 110 strands to the linear inch. The catch was extracted with 10 cc of 80% acetone and the color was compared with the standard. For measuring the density of non-colored naked flagellates, the water sample was treated with Lugol-eosine immediately after collection and counting was made within 24 hours with haemocytometer under the microscope. Supplementary observations on flagellates were carried weekly during the period of one year from June of 1948 to June of 1949, at Stations A, B, and C. Eel-grasses were sampled at Stations A and B, and stages of their cycle were decided through the observation on the growth of leaves, flowering shoots, seed formation, and degree of integration and drifting.

III. Annual cycle of ecological elements in Mangoku-ura

Generally speaking, we could see the typical cyclic change of the Inlet waters at Station A in good contrast with Station E which showed the characteristic change of outside bay water, particularly at its bottom layer. Stations B, C and D showed the intermediate features between these two extremes, each in its degree depending on the relative amount of interchanging water at high and low tides. Therefore in the following statements Station A and E will be compared in detail. The results

of observations at other stations will be referred to whenever necessary.

1. Water temperature

Fig. 3 shows the annual change of water temperature in the surface and bottom layers of Stations A and E.

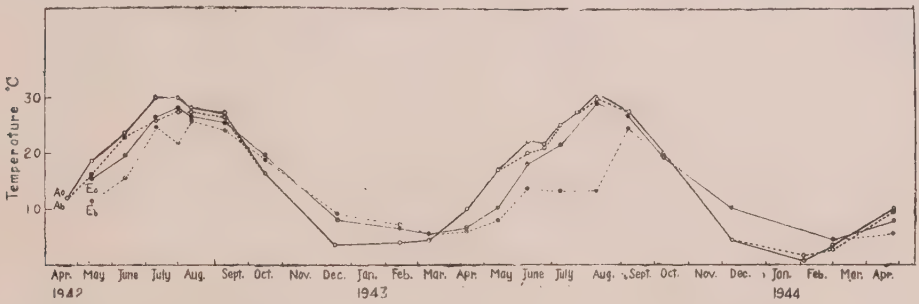

Temperature °C
30
20
10
Apr. May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. Mar. Apr.
1942
1943
1944

Fig. 3. Temperature Cycle in Mangoku-ura. A_0 and A_b indicate surface and botom of Station A, E_0 and E_b, surface and bottom of Station E.

Temperature of surface water at Station E was influenced by the outflowing Inlet water at low tide, while that of the bottom layer was not affected by such influence Therefore the changes in temperature in the bottom can be considered as representing the trend of change of the Ishinomaki Bay water. In some part of the Inlet, particularly along the periphery of the innermost region, the water temperature would occasionally drop below freezing point in January, though such a low temperature was not recorded in the survey.

From February on, the temperature rose gradually and exceeded 10°C in March and 20°C at the end of May or in early June. The peak temperature of over 30°C was read in the surface of Station A at the end of July or in early August. Not much difference was observed between the temperatures in the surface and bottom. From the middle of August, the temperature began to fall and it was 20°C in early October, 10°C in November and finally it fell as low as 2-3°C in December. On the other hand, at Station E, the rise and fall of the temperature was much retarded and the range of fluctuation lessened much, particularly in the bottom.

At Stations B, C and D, the temperature showed a mode of change similar to Station A, though some irregularities due to the influence of the inflow of bay water was noticed in accordance with the distance from the strait.

2. Salinity

Fluctuation of salinity is shown in Fig. 4 for Stations A and E. Since only a few streamlets poured into the Inlet, the salinity was kept rather high in case of no heavy rain. But once it was lowered, the recovery was slow because of the poor interchange of water with outside bay water. Such tendency was to be noticed in Fig. 4, making prolonged declines.

At Station E, the salinity was higher than at Station A. But the surface water showed the same trend of fluctuation as Station A, indicating the influence of the

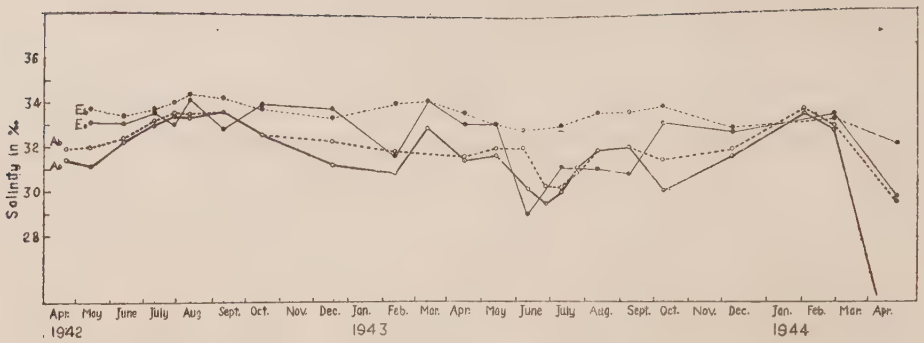


Fig. 4. Salinity in Mangoku-ura. (Signs are same as in Fig. 3.)

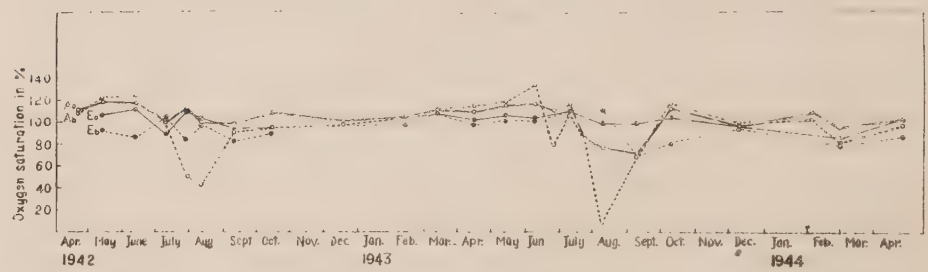


Fig. 5. Percentage Oxygen Saturation in Mangoku-ura. (Signs are same as in Fig. 3.)

outflow of Inlet water.

3. Percentage oxygen saturation

The percentage oxygen saturation was one of the most characteristic features in Mangoku-ura. It is shown in Fig. 5.

At Station A, the percentage oxygen saturation increased gradually from April on and reached a peak of 120% or over in May and June. Then a rapid fall followed which lasted until the middle of August. It recovered again to 100% and only small fluctuations were observed since then. The degradation of oxygen saturation in summer was rather prominent in the bottom, being 42% in 1942 and 10% in 1943. The increase of percentage saturation was also more marked in the bottom than in the surface. Such a wide range of variation in oxygen saturation in the bottom can be explained from the fact that the center of the photosynthesis and the disintegration of eel-grass was in the bottom water at Station A which was less aerated during the season of rising temperature.

At Stations B and C, where thick vegetation of eel-grass grew in shallow waters, the features in change of percentage oxygen saturation were rather similar to that in the bottom of Station A. Not much difference was observed between the surface and the bottom. The change of oxygen saturation in the Inlet often had influence with that of the surface water at Station E, but not with that of the bottom water.

4. Hydrogen ion concentration

pH values at Stations A and E are summarized in Fig. 6.

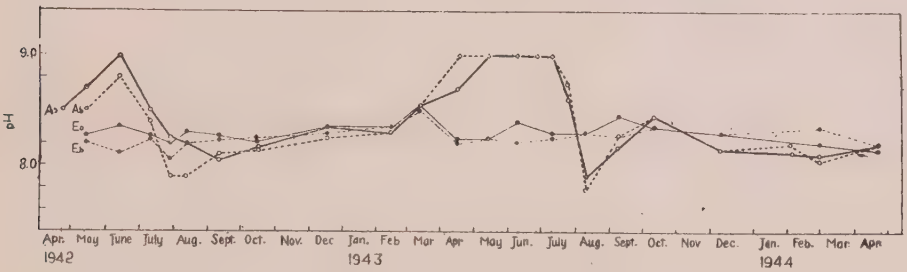


Fig. 6. pH value in Mangoku-ura. (Signs are same as in Fig. 3.)

At Station A, the pH value increased gradually from March on and showed the highest value of 9 or over in June. Then it fell until the lowest value of 7.8–7.9 was reached in early August. It recovered again to 8.1–8.2 level in early September and remained there through the fall and the winter. Such marked changes of pH during spring and summer were respectively due to the photosynthetic activity and decomposition of eel-grass as will be stated later. The mode of change reflected itself on the changes in percentage oxygen saturation already referred to. At Station E, the range of fluctuation was very narrow. But the surface layer was occasionally influenced by the outflowing water of the Inlet during low tide.

Ishida (1935) demonstrated an increase of oxygen saturation and increase of pH value as a result of solar illumination in the sound covered with eel-grass. He observed the biggest change on August 4, when oxygen saturation increased from 70 to 120% and pH value from 8.1 to 8.35 in 5 hours, beginning 9 o'clock in the morning. Hourly increase became smaller in the colder season. However in his last observation, on December 5, he detected a slight but steady increase of the degree of oxygen saturation and pH value in daytime, indicating the vegetative activity of eel-grass.

5. Nutrient salts

The results of inorganic phosphate determinations at Stations A and E are shown in Fig. 7.

At Station A, the amount of inorganic phosphate began to increase in early June and reached the highest value of 150 mg of P_2O_5 per cubic meter in early August. Then it took a rapid drop and by October it decreased to as low as 10–30 mg per cubic meter. Since then it remained at this level with slight fluctuations through the cold season until a new cycle of increase occurred in the next summer. Such conspicuous increase of phosphate during summer was also observed occasionally in the surface water of Station E as a result of outflow of the Inlet water, but not in the bottom. High phosphate content during the summer season was considered doubtlessly due to the liberation of phosphate through disintegration and decomposi-

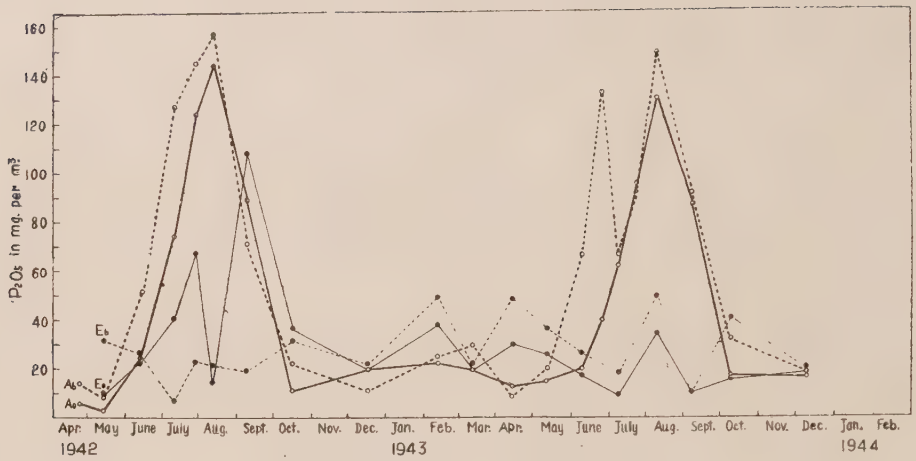


Fig. 7. Phosphate in Mangoku-ura. (Signs are same as in Fig. 3.)

tion of eel-grass as will be referred to later.

It seems worth mentioning that the liberated phosphate did not remain but disappeared rapidly and once it had reached a level as low as 10–30mg per cubic meter, it remained at this level during the rest of the season. The amount of phosphate during this period was even less than that of Station E.

A vast amount of liberated phosphate could be available for the production of floating colored algae including diatoms, together with other nutrient salts. But practically no evidence was observed to indicate that they were used for the outburst of phytoplankton. Therefore a rapid disappearance of phosphate should have some other cause to be explained. It was more likely that large parts of the liberated phosphate were removed to the bottom by absorption and sedimentation of particulate matter.

Though detailed analysis is necessary before we can discuss the fate of liberated phosphate in the Inlet, it can be assumed from these evidences together with the vegetative cycle of eel-grass, that a large part of liberated phosphate is held in the bottom and is ultimately used for the growth of eel-grass and only a small part is regenerated from the bottom and returned to the cycle of primary production in water, during fall and winter.

Seasonal change in silicate showed a characteristic of fluctuation similar to that of phosphate, though it was more irregular as compared to the latter. The results are shown in Fig. 8.

As for nitrogen compounds, both nitrate and ammonia showed changes similar to that of phosphate and silicate, namely high concentrations in summer followed by low ones during the rest of the year with certain fluctuations.

6. Phenology of eel-grass in Mangoku-ura

The characteristic cycle of the chemical nature of Mangoku-ura water is virtually

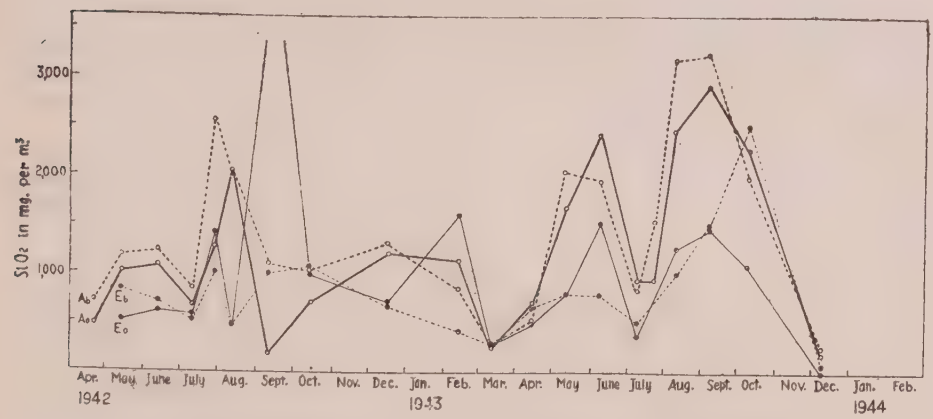


Fig. 8. Cycle of Silicate in Mangoku-ura. (Signs are same as in Fig. 3.)

controlled by the life cycle of eel-grass which covered almost 80% of the area of the Inlet. The phenology of *Zostera marina* has been reported in detail by Setchell (1929). Arasaki (1950) reported the cycle in Ikawazu. Generally speaking, we found cyclic changes in Mangoku-ura similar to those described by these authors. The vegetative activity became prominent in March when the water temperature reached 10°C and growth was accelerated. Flowering shoots appeared in April and when the temperature exceeded 20°C in May, flowering began and the growth of leaves reached the maximum. At Station A, they were measured 3 meters long at least and at other shallow Stations B and C 2 meters long. At this stage the tops of leaves had already begun disintegration. Fruit began to mature from the middle of June, when the temperature was around 25°C and the flowering shoots were detached and drifted. Disintegration and drifting of leaves gradually became prominent and reached their maximum in the middle of August. By this time, most of the old leaves were detached from the plant and olny new leaves and buds were left. These new leaves grew slowly during colder seasons until they regained high vegetative activity in spring. Thus, the annual cycle of eel-grass in Mangoku-ura can be divided into several stages : stage of active vegetation in March and April ; of flowering in May ; of fruit maturing and beginning of disintegration in June, of intensive disintegration and decomposition in July and August and of slow growth in fall and winter months.

As already stated, nearly 1,500 acres of Mangoku-ura bottom are densely covered with eel-grass, so that the amount of grass which runs into decaying in summer should be enormous. We have no data available for the estimation of the actual amount. But if we apply the figure given in Ikawazu by Arasaki, we will be able to make a rough estimate. He estimated the average weight of grass in one square meter at the stage of maximum growth as 400 grams and as 200 grams after summer disintegration. It means that 200 grams of grasses were disintegrated and

decomposed for each square meter. From our observation it was assumed that nearly three quarters of a plant was lost during summer. If these figures be applied, 1,400–2,200 tons of eel-grass were expected to disintegrate and decompose in Mangoku-ura in every summer.

7. Seasonal variation of flagellate population in Mangoku-ura

It is naturally expected that the cyclic change of the ecological elements in Mangoku-ura water might have influence on the production of microplankton in the Inlet.

Prefectural Fisheries Experiment Station at Watanoha, conducted a few oceanographic surveys of the Inlet in connection with seed-oyster production. However, most of their results being fragmental and not satisfactory, it is difficult to draw a general conclusion as to the standing crop of plankton throughout the year. According to the report in 1933, during summer net haulings revealed poor population of phytoplankton but rich organic detritus, but there seldom occurred outbursts of diatoms such as *Chaetoceras*.

In the present survey, we could not make a detailed study of the phytoplankton population. But, in order to grasp the relative abundance of phytoplankton at various seasons of the year, the amount of chlorophyl pigment was determined for sampled plankton by Harvey's method of acetone extract, during the period of 1943–1944.

At Station A, 500-600 units of pigments per cubic meter were measured in March and April. It was 300–500 units throughout June, July and August and 100–300 units in fall and winter months. Though the determinations were made at long intervals, we can see from these figures that the phytoplankton production of the Inlet was rather low, and that large amounts of nutrient salts liberated by decomposition of eel-grass in summer did not contribute to sustain a high standing crop of phytoplankton. Occasional outbursts of phytoplankton indicated that some parts of the nutrient salts had returned to the production cycles. But such phenomenon occurred only locally and lasted for a short period.

The seasonal fluctuation of non-colored, naked flagellates, on the contrary, showed a characteristic cycle in accordance with the cyclic changes of the Inlet water. Counts of non-colored flagellates were made with samples of water into which Lugol-eosine was added right after collection. No preservatives were used. When we added the dye solution as much as one tenth of the volume of sea water, the flagellates were kept in good shape for counting as long as 48 hours. Usually they were counted within 24 hours after sampling. The results for the period of 1942–1943 were, however, not accurate enough, because the amount of dyes used was too small. Therefore, only the results of count at Stations A and E for the period of 1943–1944 are shown in Fig. 9.

There was a conspicuous increase of non-colored, naked flagellates during the period from June to early September, with the peak density of over 5,000 per cc in

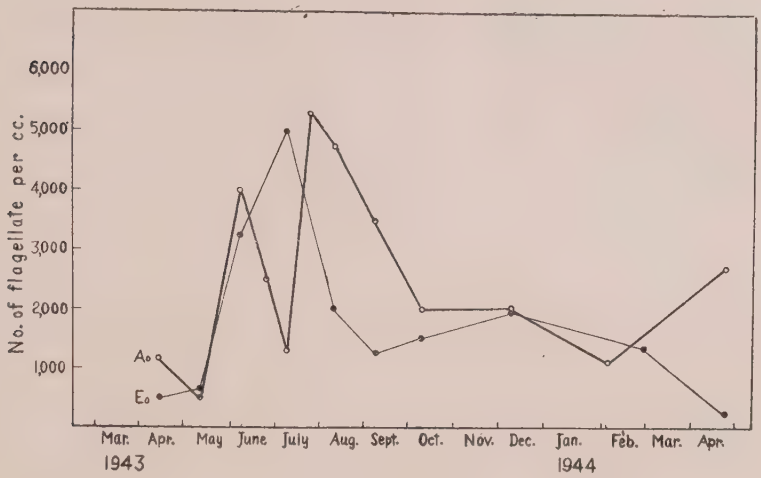


Fig. 9. Abundance of non-colored naked flagellates in Mangoku-ura, for the period of 1943–1944.

August. From September on, the density dropped as low as 2,000 or less and stayed at a low level during winter and spring. These non-colored, naked flagellates had a holozoic mode of nutrition (Imai *et al.*, 1950) and their density curve would fluctuate greatly because of its rapid propagation and disintegration. Therefore in order to see the seasonal changes more in detail, weekly observations were made at several stations in the Inlet during the period of 1948–1949. The result obtained at Station C is shown in Fig. 10.

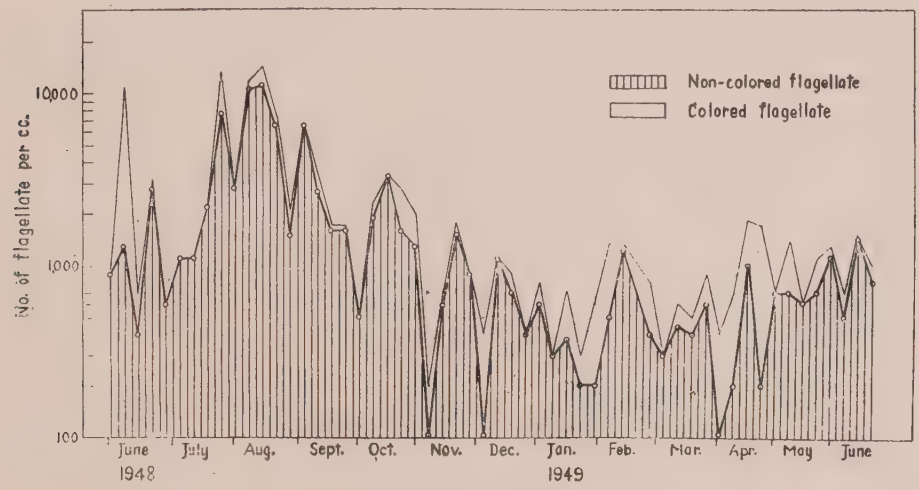


Fig. 10. Abundance of flagellates in Mangoku-ura for the period 1948–1949. Weekly observation. Number of flagellates is expressed on logarithmic scale.

In the observation, the count was also made on colored flagellates besides the non-colored ones. Though there were several forms of non-colored flagellates differing in size and in flagellum, they were counted as a whole. However, they mainly consisted of the forms presumably identified as *Monas* sp. in our breeding experiment (Imai *et al.*, 1949 and 1950). Though some fluctuations were observed, the general trend of seasonal change was similar to 1943–1944 season. In July, the density exceeded 1,000 per cc and continued to increase rapidly till it reached the peak of over 10,000 per cc in August. Then it dropped gradually and in October it was of the order of 1,000 per cc. During winter and early summer it fluctuated around the level of 500–1,000. The population of the colored type of flagellate was rather small in number as compared to the non-colored type. It was noticed that during the hot season when the density was very high, the colored type occupied a much smaller part of the whole population and in spring and fall *vice versa*.

The occurrence of such a high density of non-colored flagellates during summer undoubtedly resulted from the organic decomposition of eel-grass in the Inlet as was already described. The population density seemed to fluctuate in parallel with the amount of decomposing eel-grass which reached its maximum in August. Though the lower temperature lessened the rate of increase, the low density of non-colored flagellates observed in fall and winter should be the result of an inadequate supply of organic enrichment.

The decomposition of vast amounts of eel-grass resulted in a heavy growth of bacteria which in turn resulted in the heavy growth of non-colored, naked flagellates during summer. Korringa (1949) also recorded an occurrence of high density of small, naked flagellates of 1,000–8,000 per cc in Oosterschelds, Holland.

Biological significance of heavy growth of non-colored, naked flagellates in the region of the seed-oyster production will be discussed in the following chapter.

IV. Conclusions on the relation of the ecological cycle to the seed-oyster production and other culture industry in the Inlet.

The cyclic changes of various ecological elements of the Inlet are summarized diagramatically in Fig. 11. The figure illustrates how the life cycle of eel-grass governs the ecological conditions in the Inlet. It also shows the correlation among various ecological elements.

As already stated in the introduction, the main fishery industries in the Inlet are seed-oyster production, culture of edible oyster and laver culture. The annual seed-oyster production amounts to 200,000-500,000 "*rens*" which is next to 1,500,000 "*rens*" produced in Matsushima Bay.

Main spawning of oysters in the Inlet usually occurs three times during July and August. Oysters reach full maturity at the end of June when the water tem-

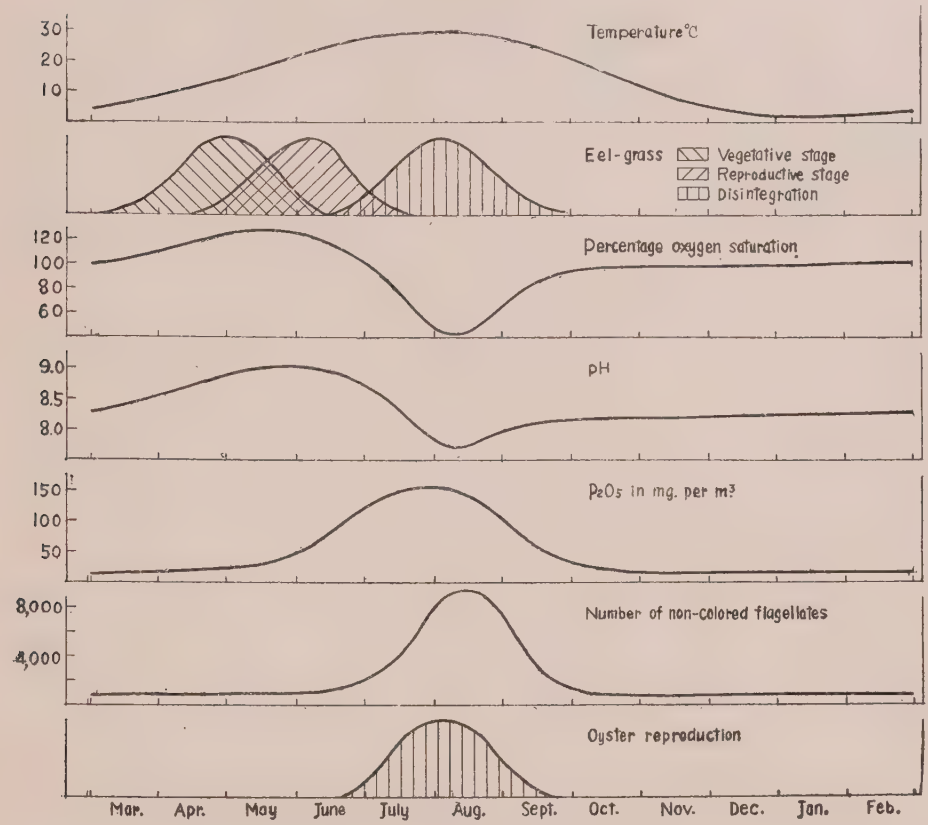


Fig. 11. Diagramatic illustration of the relation between changes of various ecological elements in Mangoku-ura.

perature rise above 20°C and they are ready to spawn in early July. Among these spawnings, those of middle of July and early August usually result in successful setting while that of late August rarely gives a good set because of the lowering temperature. Sometimes a small spawn occurred as late as September but most of the larvae failed to survive to make a good set. Under such conditions, the main larval life which led to the production of seed-oysters in the Inlet extended from the middle of July to the end of August.

Actual count of larvae revealed that during the period of maximum occurrence 500 to 2,000 larvae were counted in 100 liters of water. For the successful growth of large numbers of oyster larvae, enough food should be provided. When we consider the occurrence of a dense larval population of other bivalves at the same time, the amount of food organisms required by these larvae should be enormous.

We have reported that a form of non-colored, naked flagellate, *Monas* sp., isolated from the Inlet served as a favorable food for oyster and other bivalves. From the laboratory experiment as well as from the observations on the population of non-colored flagellates in the Inlet, we may properly conclude that in Mangoku-ura, the

continuous outburst of the flagellates during summer provides it the favorite food condition for the growth of dense larval population, though it may not be the sole food organism. In our tank breeding, it was shown (Imai *et al.*, 1950) that a density of *Monas* sp. of the order of 2,000–3,000 per cc of water sufficed to feed a population of larvae of 100 per liter. During the breeding season of oysters in Mangoku-ura, the density of non-colored, naked flagellates was over 2,000 per cc and it reached as high as 10,000 per cc or over in August. Such a high density may possibly be sufficient to feed the larval population already mentioned. From such consideration, we may say that the production of seed-oysters in the Inlet is assured in respect of food supply through the decomposition of vast amounts of eel-grass. No other organic enrichment which possibly gives the same effect can be considered in Mangoku-ura.

The ecological condition related to the seed-oyster production in Matsushima Bay is considered as similar to Mangoku-ura in its dependence on the life cycle of eel-grass. In Matsushima Bay, however, there seems to be additional enrichments due to the inflow of river water and of organic pollution in the fishing port of Shiogama.

Mangoku-ura also produced sea-cucumbers. They spawn in the Inlet during June and July. We have shown that (Imai *et al.*, 1950) we could rear the larvae on the same diet as oyster larvae. Therefore the natural propagation of sea-cucumbers is also favored by the decomposition of eel-grass for their larval growth.

Culture of edible oysters and laver are the important culture industries in the Inlet. The racks and rafts are set up in channels or in water near the mouth of the Inlet and from them cultch is hung down by rope for culture. Details of the culture method prevalent in this district has been described by Glud (1949) and Cahn (1950). In 1950, nearly 20,000 "*kan*" of shucked oysters were produced. However, the growth and fattening of oysters in this Inlet were by no means good. Poor quality of oysters was more noticeable when larger amounts were cultured. Such fact can be explained by the low fertility of the Inlet water with only a small amount of micro-plankton available for oyster as food during spring and fall.

The laver culture in the Inlet also suffers from the deficiency of nutrient salts. Young leaves of laver on brush or coil suspended in the water grow by photosynthesis in the presence of a sufficient amount of nutrient salts. Though these salts are liberated as a results of decomposition of eel-grass during summer, they are largely absorbed by sediment and do not return to production cycle in the water, and moreover only a small amount of nutrient salts will be added from the outside bay water. Under such ecological conditions of the Inlet, we can not expect the production of laver of good quality unless the water is fertilized otherwise.

Thus we may say that a dense vegetation of eel-grass certainly does not favor the culture of oysters and laver which need a sufficient supply of nutrient salts.

From these evidences and consideration, we may conclude that in Mangoku-ura,

a dense vegetation of eel-grass governs almost definitely the cyclic change of the Inlet water. It brings a condition favorable for the production of seed-oysters and young of sea-cucumbers during summer while it sets rather unfavorable conditions for the culture industry which depends upon the fertility of water during seasons of lower temperature. Such seemed to be the characteristic feature of Mangoku-ura which should be taken into consideration whenever we make plans for the efficient utilization of the Inlet for culture purpose.

REFERENCES

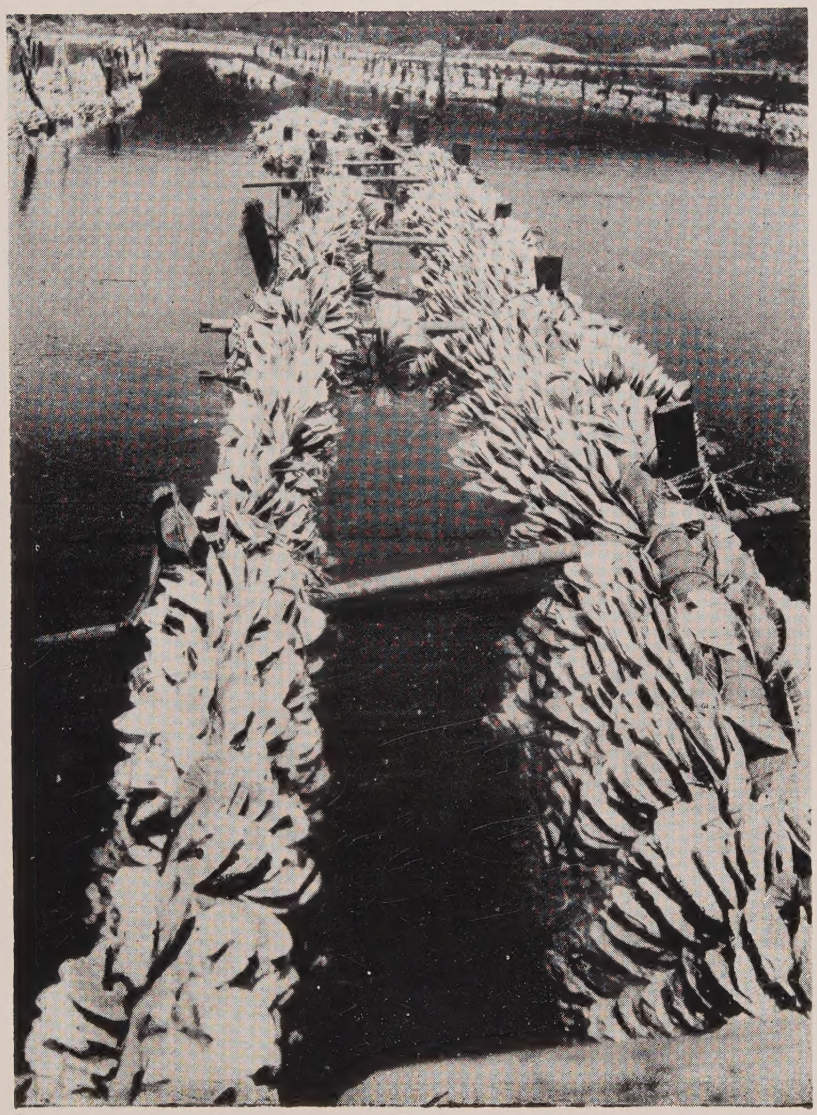
(1) Arasaki, S., Bull. of the Jap. Soc. of Sci. Fish., **15** (1949), 567, and **16** (1950), 70.
(2) Cahn, A. R., Oyster culture in Japan. Report No. 134, Natural Resources Section, GHQ, SCAP, in Japan (1950).
(3) Glud, J. B., Comm. Fish. Rev., **11** (1949), 1.
(4) Glud, J. B. and C. E. Lindsay, Japanese oyster seed export program for 1949. Preliminary Study No. 10 of the Natural Resources Section, GHQ, SCAP, in Japan (1949).
(5) Imai, T. and M. Hatanaka, Bull. of the Inst. for Agric. Research, Tohoku Univ., **1** (1949), 33.
(6) Imai, T. and M. Hatanaka, Sci. Rep. of Tohoku Univ., 4th Ser., **18** (1950), 304.
(7) Imai, T., M. Hatanaka, R. Sato, S. Sakai and R. Yuki, Tohoku Jour. of Agric. Research, **1** (1950), 69.
(8) Imai, T., D. Inaba, R. Sato and M. Hatanaka, Bull. of the Inst. for Agric. Research, Tohoku Univ., **2** (1950), 275.
(9) Ishida, S., Dobutsu and Shokubutsu (in Japanese), **3** (1935), 73.
(10) Jensen, P. B., Danish Biol. Sta. Repts., **22** (1914), 1.
(11) Marine Meteorological Observatory of Kobe : Kaiyo-Kansoku-Ho (Method of Oceanographic Research) (1940).
(12) Korringa, P., Bijdragen tot de Dierkunde, **28** (1949), 237.
(13) Miki, S., Botanical Magazine, **47** (1933) 842 : **48** (1934), 131, 171.
(14) Miyagi Prefectural Fisheries Exp. Station, : Annual Reports for 1933 and 1936.
(15) Petersen C. G. J., Danish Biol. Sta. Repts., **25** (1918), 66.
(16) Setchel, W. A., Univ. of Calif. Public. in Botany, **14** (1929), 389.

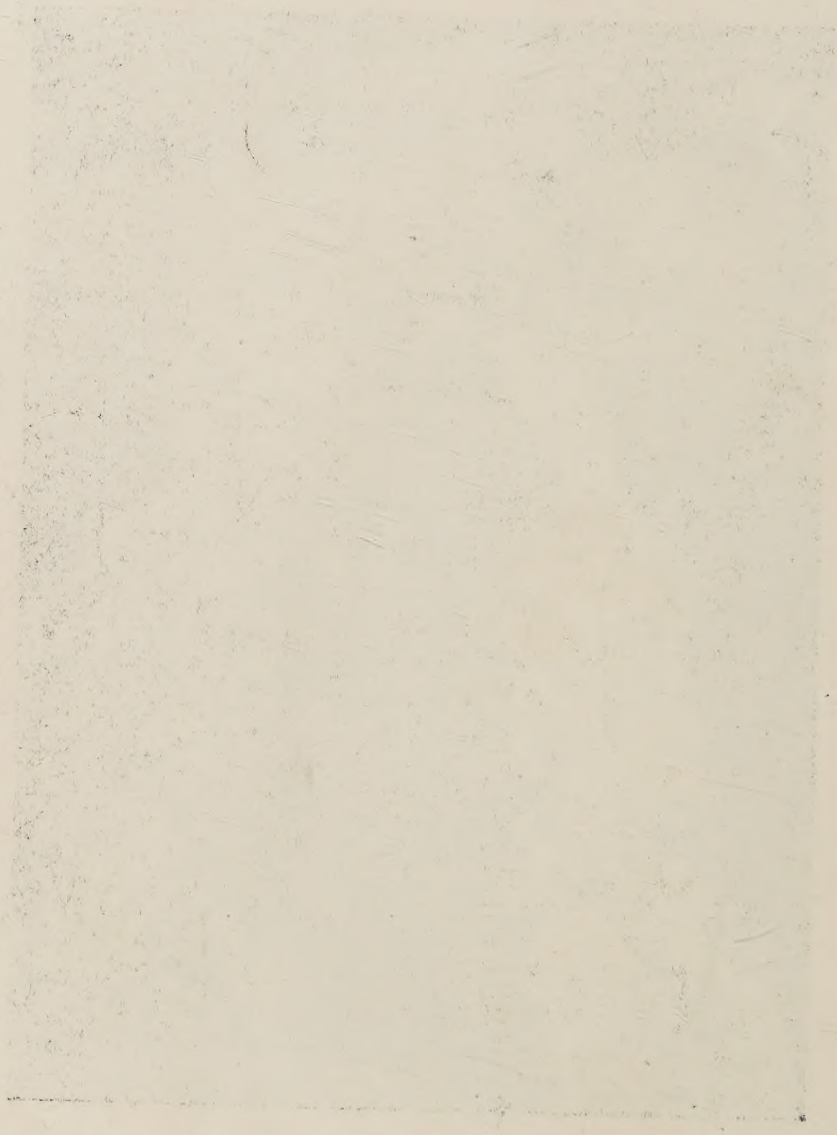
EXPLANATION OF PLATES

Plate I and II. Views of Seed-oyster Production in Mangoku-ura.

Plate I.

Plate II.





東北大學研究所報告
(農　学)
第1—2卷合併号

昭和26年3月25日印刷
昭和26年3月30日発行

編集者　寿時富彌
仙台市片平丁75 金属材料研究所内
東北大学研究所連合会
発行者　木村次郎
東北大学農学研究所
仙台市片平丁41番地
印刷者　笹氣幸助
印刷所　笹氣出版印刷株式会社
仙台市堤通27　電話3227番

Printed by
SASAKI PRINTING & PUBLISHING Co., Ltd.
27, Tsutsumi-dôri, Sendai, Japan.

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